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MAY 80 G J BARBATO, R P MADERO, G A SEXTON F33615-78-C-3614
UNCLASSIFIED AFWAL-TR-80-3030-VOL-1 NL

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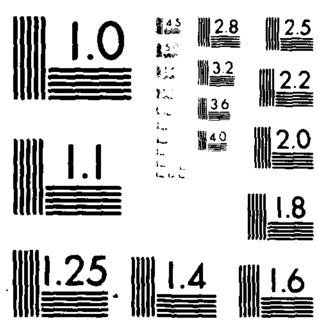
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AFWAL-TR-80-3030
Volume I

LEVEL

AD A088034

TANKER AVIONICS/AIRCREW COMPLEMENT EVALUATION (TAACE)
PHASE 0 - ANALYSIS AND MOCKUP

VOLUME I: RESULTS

The Bunker Ramo Corporation
Electronic Systems Division
Westlake Village, California

May 1980

TECHNICAL REPORT AFWAL-TR-80-3030, VOLUME I

Final Report for Period June 1978 - May 1979

Approved for public release; distribution unlimited.

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This technical report has been reviewed and is approved for publication.

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Field	Entry
1. REPORT NUMBER	AFWAL-TR-80-3030, Vol-I
2. GOVT ACCESSION NO.	AD-A088 034
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle)	Tanker Avionics/Aircrew Complement Evaluation (TAACE) Phase 0 Analysis and Mockup, ~~Final Report~~ Volume I, Results
5. TYPE OF REPORT & PERIOD COVERED	~~Technical~~ Final 4 Jun 78 — 31 May 79
6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s)	Gregory J. Barbato, Ralph P. Madero, George A. Sexton, Richard W. Moss, Maj William R. Brandt
8. CONTRACT OR GRANT NUMBER(s)	F33615-78-C-3614
9. PERFORMING ORGANIZATION NAME AND ADDRESS	Bunker Ramo Corporation, 4130 Linden Ave., Dayton, Ohio 45432
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	11142F 23915100
11. CONTROLLING OFFICE NAME AND ADDRESS	Air Force Wright Aeronautical Laboratory, Flight Dynamics Laboratory (AFWAL/FIGR), Wright-Patterson Air Force Base, OH 45433
12. REPORT DATE	May 1980
13. NUMBER OF PAGES	163
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	
15. SECURITY CLASS. (of this report)	Unclassified
15a. DECLASSIFICATION DOWNGRADING SCHEDULE	

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

This work was performed by the contractor on-site at the Flight Dynamics Laboratory, Flight Control Division, Crew Systems Development Branch, WPAFB, OH

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

KC-135
Advanced Crew Systems
Inertial Navigation System
Avionics Modernization
Horizontal Situation Display
Navigator
Crew Size
Workload
Tanker
Control/Display Criteria
Strategic Air Command
Mockup Evaluation

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This report documents a mockup cockpit design study which was performed in support of the USAF KC-135 Avionics Modernization Program. The preliminary issues addressed during the study were the avionics control and display criteria to be met in the event of a reduction in crew size for the KC-135. The study results indicated that two pilots and a boom operator could successfully fly the depicted mission scenario by reallocating various crew tasks and by utilizing 1980 state-of-the-art avionics/navigation systems.

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This report is presented in three volumes. Volume I describes the TAACE program and the mockup evaluation results. Volume II is a summary of the data resulting from the study, and Volume III is a detailed description of the mission scenario used during the evaluation.

FOREWORD

This report documents the first phase of a two-phase effort called the Tanker Avionics/Aircrew Complement Evaluation (TAACE). The results obtained in an experimental cockpit mockup design effort concerned with developing the crew station avionics criteria to be met for a 3-man crew complement (pilot, copilot, boom operator) to complete all KC-135 mission requirements without compromise to either mission performance or aircraft operational safety are reported herein.

The program is being conducted under an Air Force Systems Command Memorandum of Understanding between the Aeronautical Systems Division, KC-135 Avionics Modernization Program Office (ASD/SD-28) managed by Mr. Tom Biggs, and the Flight Dynamics Laboratory (AFWAL/FIGR), Wright-Patterson AFB, Ohio. The Flight Dynamics Laboratory portion of the program is managed by Mr. Richard Moss, Program Manager, AFWAL/FIGR, and Lt Donald Seyler, Lead Engineer: Crew Systems Design Phase, AFWAL/FIGR.

The report was prepared in part by the on-site Human Factors Group, located at Wright-Patterson AFB, Ohio, Electronic Systems, Bunker Ramo Corporation, Westlake Village, California, under USAF Contract No. F33615-78C-3614, Project No. 23915100. Mr. Robert A. Bondurant, III (AFWAL/FIGR) is the contract monitor.

The authors wish to acknowledge the assistance from Lt Mark Hussey and Lt Tom Roberts, formerly of AFWAL/FIGR, for their essential contributions concerning the present study experimental design and set-up, testing, and report preparation. In addition, recognition is given to Mr. Tom Molnar (AFWAL/FIGL) for critical assistance in the development of the nav management system; Mr. John Kozina (Bunker Ramo) and Mr. Fritz Baker (Lear Siegler) for engineering assistance in experimental equipment integration; Mr. Rick Helton and Mr. Tom Payton (AMFTD) for construction of the KC-135 mockup; Capt Steve Kolet (AFWAL/FIGX) for extensive consulting regarding KC-135 operations; and Cindy Gier and Sandy Dickey (Bunker Ramo) for untiring administrative support.

This research effort was performed between June 1978 and May 1979.

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LIST OF ABBREVIATIONS

A/A	Air to Air
AC	Alternating Current
ADF	Automatic Direction Finding
ADI	Attitude Director Indicator
AFFDL	Air Force Flight Dynamics Laboratory
AHRS	Attitude Heading Reference System
APU	Auxiliary Power Unit
A/R	Air Refueling
ARA	Airborne Radar Approach
ARCP	Air Refueling Control Point
ARCT	Air Refueling Control Time
ARIP	Air Refueling Initial Point
ATC	Air Traffic Control
BAR	Begin Air Refueling
BDHI	Bearing Distance Heading Indicator
CADC	Central Air Data Computer
CAS	Calibrated Airspeed
C/D	Control/Display
CDU	Control/Display Unit
CG	Center of Gravity
CONUS	Continental United States
CRT	Cathode Ray Tube
DC	Direct Current
DF	Direction Finder
DME	Distance Measuring Equipment
DR	Dead Reckoning

LIST OF ABBREVIATIONS
(cont.)

EAR	End of Aerial Refueling
EGT	Exhaust Gas Temperature
EMP	Electromagnetic Pulse
EPR	Engine Pressure Ratio
FL	Flight Level
FM	Frequency Modulation
GA	Go Around
GCI	Ground Controlled Intercept
GMT	Greenwich Mean Time
GS	Groundspeed
HF	High Frequency
HSD	Horizontal Situation Display
HSI	Horizontal Situation Indicator
IAS	Indicated Airspeed
IFF	Identification, Friend or Foe
IFF/SIF	Identification, Friend or Foe/Selective Identification Feature
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
INS	Inertial Navigation System
JN	Jet Navigation
MPD	Multipurpose Display
MRT	Military Rated Thrust
NATO	North Atlantic Treaty Organization

LIST OF ABBREVIATIONS
(cont.)

NM	Nautical Miles
PPSN	Present Position
RGA	Rotate and Go Around
RMI	Radio Magnetic Indicator
RPM	Revolutions Per Minute
R/T	Receiver/Transmitter
RZ	Rendezvous
RZIP	Rendezvous Initial Point
SAC	Strategic Air Command
SELCAL	Selective Call
SKE	Station Keeping Equipment
TAACE	Tanker Avionics/Aircrew Complement Evaluation
TACAN	Tactical Air Navigation
TAS	True Airspeed
TOLD	Take-Off and Landing Data
TRT	Take-Off Rated Thrust
UHF	Ultra High Frequency
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VOR	VHF Omnidirectional Range
VVI	Vertical Velocity Indicator
WX	Weather

SUMMARY

This report documents a mockup cockpit design study which was the first phase of a two-phase effort currently being performed in support of the USAF KC-135 Avionics Modernization Program. The report is presented in three volumes: Volume I describes the experimental design and summary of results; Volume II presents the study data; and Volume III details the mission scenario.

To address the cockpit design issues relating to eliminating the navigator from the KC-135 tanker aircraft, a full scale mockup was designed and was "flown" by operational aircrews over a representative mission profile. The results of the study are presented in this paper. To develop the experimental design around answering the question of how to eliminate the navigator position from the aircraft, a mission analysis and composite mission scenario were constructed, and three candidate suites of available control/display avionics were identified and arranged in the full-size representative KC-135 cockpit mockup. Nine fully qualified Strategic Air Command tanker (KC-135) aircrews, consisting of two pilots and a boom operator, "flew" the composite mission scenario and the three candidate avionics suites. They thereby provided a subjective data base that formulates the results and conclusions of the present study.

The primary issues addressed during this study were the avionics control and display criteria to be met in the event of the reduction of the crew complement for the KC-135. The resultant data of the experiment suggested that subject crews were strongly supportive of a reduced crew complement only if certain present and useful KC-135 avionics hardware is relocated while other hardware that has become unacceptably outdated or has outlived its usefulness is significantly updated. The crew members were very much in favor of including as new hardware a navigation management system that could display at least six upcoming waypoints at a time with an almost infinite waypoint storage capacity. Additional capabilities of the system included fuel management/status update and display, automatic present position update in relation to flight plan, and the ability to calculate center of gravity and takeoff/landing computations. During refueling operations, holding and rendezvous patterns could also be preprogrammed into the system.

Another major modification to the cockpit design which was judged by the crews to be indispensible for mission accomplishment with a reduced crew size was the horizontal situation display. This device, which replaced the standard horizontal situation indicator, not only could display that standard information, but also allowed the selection of a moving map alone or with weather, ground mapping, or radar beacon overlays. In addition, certain

other flight parameters such as glide slope, groundspeed, course, and time and distance to the next waypoint were available on the perimeter and at the corners of the display itself.

Other changes to the current KC-135 avionics layout rated highly by the crew members were the use of vertical-scale engine instruments and the inclusion of a caution/warning annunciator panel. This panel consolidated all caution and warning indicators into one area of the front instrument panel directly in view of the pilot and copilot. The panel area was made available through the use of the vertical-scale instruments.

It should be noted that although the crew station reconfigurations presented in this report were analyzed in the context of a reduced crew complement (i.e., without a navigator), many of the findings about enhanced ability to accomplish the mission while, at the same time, reducing crew workload are applicable even without eliminating the navigator crew position. Given the rapidly increasing amount of information that must be assimilated by the pilot and copilot in a potentially expanding hostile environment, it becomes imperative that advanced technology in the form of multipurpose displays and computers be incorporated in crew systems designs to perform some of the paperwork/navigation computations which presently consume a significant amount of time and substantially contribute to aircrew workload.

Based on the results of this study, it can be stated that accomplishment of the aerial refueling mission is feasible with a two pilot, one boom operator flight crew by reallocating crew tasks and by utilizing 1980 state-of-the-art crew systems, including a navigation management system, electronic horizontal situation/multipurpose displays, and generally upgraded avionics systems.

SECTION I

INTRODUCTION

Background.

Recognizing the potential for significant cost savings to the Air Force if the navigator position could be eliminated from the KC-135 tanker flight crew, the USAF has directed that a program be undertaken to determine the feasibility of replacing the navigator with cost effective avionics and/or other cockpit modifications. In support of this effort, the AF Flight Dynamics Laboratory has undertaken a program that will identify the criteria to be met by the avionics and other cockpit modifications necessary for a 3-man crew complement (pilot, copilot, boom operator) to complete all KC-135 mission requirements without compromises to either mission performance or aircraft operational safety. This effort is called the Tanker Avionics and Aircrew Complement Evaluation (TAACE) Program and is a two-phase effort, starting with mission analysis and mockup design evaluation and progressing to mission simulation validation.

In establishing an experimental mockup evaluation, TAACE personnel relied most heavily upon the information acquired during an intensive mission analysis phase. This portion involved numerous observation flights in which the crew positions of pilot, copilot, navigator, and boom operator were critically evaluated. Crews were administered mission analysis questionnaires which were geared to crew position and mission segment and required them to analyze their workload as a function of mission type and segment. Through these flight observations and completed questionnaires, crew tasks were identified, the major elements of representative KC-135 tanker mission sorties were established, and the functioning of the present tanker crew systems were reviewed. Interviews with members of SAC tanker crews and special SAC mission briefings provided the final information necessary to tie together all the data gathered during mission analysis, and allowed the crews an additional avenue to express their concerns and preferences related to removing the navigator from the cockpit. This mission analysis work, in conjunction with the knowledge and experience gained in the crew station design area from involvement in previous transport programs, enabled a candidate cockpit design to be devised. This design (referred to as the moderate update) included the moving forward of instrumentation from the navigator's station to where it could be accessed by the pilots, and upgrading and relocating other crew systems to enhance their utilization and reduce crew workload. This moderate update was regarded as being most representative of the degree of avionics sophistication that would be necessary in order for the air refueling mission to be accomplished without a navigator.

Following this, so as to give the mockup evaluation a broadened spectrum of design capabilities for subsequent crew analysis, two additional configurations were created (the minimum and the major updates). The minimum update basically consisted of the present KC-135 flight deck, except that a dual inertial navigation system (INS) was added and the required items were brought forward from the nav station for pilot usage. It was felt that this update did not represent enough avionics sophistication for a two pilot, one boom operator flight crew, but exposing the subject crews to such a system enabled them to better evaluate the moderate update for potential over-sophistication. The minimum update represented the least expensive configuration to implement in the tanker. On the opposite end of the design spectrum, the major update was configured with the greatest amount of crew systems avionics sophistication of the three update designs. As one example, the major update contained nine cathode ray tube (CRT) displays as compared to the moderate update's four CRTs and the minimum's one CRT, which was actually the radar scope currently being used on the KC-135. Because the major update was deliberately configured with a greater amount of crew systems capabilities than was felt to be required for a reduced flight crew, subjects were given more flexibility in determining the degree of avionics sophistication necessary beyond that offered by the moderate update. The net effect of these three systems candidates was to expose the subject crews to a wide latitude of design capabilities and to enable them to respond to these concepts on either side of the moderate update configuration.

Objectives.

The goal of the TAACE mockup evaluation phase was to explore preliminary design trades toward the realization of a two-pilot, one boom operator crew complement. The design trades were investigated by having subject crews "fly" representative KC-135 mission scenarios and evaluate the cockpit configurations with which they were presented. The data collected consisted of subjective opinions but objective measurements of workload levels were also attempted. Throughout the entire mission analysis and mockup evaluation phase, intensive coordination with HQ SAC personnel in XPH and DOT occurred regarding the mission scenarios flown by the subject crews and the fact that the boom operator would be treated as a positive control crew member to help with the increased workload resulting from the elimination of the navigator.

Evaluation of the collected data yielded a composite design which embodied the most favorable aspects of the three update configurations. This composite design is described in Section V, and will be experimentally evaluated during the next phase of the TAACE program -- simulation validation.

SECTION II

METHODOLOGY

Subjects. Nine crews were the participants in this experiment. Each crew consisted of a pilot, a copilot, and a boom operator. The average experience of the pilots was 2361.6 hours flying time on a total of 14 different aircraft with the copilots averaging 1478.8 hours on seven different aircraft, and the boom operators averaging 1060.5 hours on the KC-135 (one boom operator had logged a total of 3500 hours on the KC-97). All crews were selected by Strategic Air Command and covered a wide range of experience levels. Table 1 depicts the crews' home bases and their respective experience levels.

Mission Scenario. A KC-135 mission scenario was developed which encompassed all types of mission tasks, meteorological conditions, all formations, instrument approaches, and hostile environment conditions which the tanker would be expected to encounter. It also included multi-ship as well as single-ship formations.

This scenario was divided into three sorties. A detailed narrative of each follows.

LORING TO U.K. FIGHTER DEPLOYMENT SUPPORT
(LEG 1)
(Figure 1)

The 3905 Strategic Aerial Refueling Wing, Loring AFB has been alerted for a Coronet mission to support an increased readiness posture in Europe. A deployment frag is dispatched which directs a five ship tanker force from Loring AFB to support an A-7 unit deployment from McGuire AFB to RAF Wittering. Proposed launch time is 1100Z which is three hours from now. The mission is identified as Coronet Eagle.

Eagle Tanker crews attend the deployment mission briefing which covers crew and aircraft assignment, spares, fuel loads (160,000 pounds), parking spots, navigation routing, procedures for marshalling, departure, formation, join-up, cruise, rendezvous, refueling, and recovery. Status of tanker force is identified as preflighted, but not cocked. Airborne command post (call sign, Head Dancer), airborne search and rescue (call sign, Duckbutt), weather and alternate recovery procedures are also detailed. An intelligence briefing outlining the European political instability and prognosis of deterioration completes the mission briefing. Eagle crews receive mission kits, obtain a time hack and disburse to complete individual nav planning and pre-departure tasks. The following scenario described the activities of the crew in the #2 ship (call sign, Esso 2) of the five ship cell (Esso 1 thru 5)

Table 1. Subject Profile

Crew	Aircrew Position	KC-135 Hours	Total Hours*	Simulated EWO	Single tanker/ Cell of receivers	Cell Lead	High Latitude	Overwater Fighter drag	#2 or 3 in cell
1-Barksdale	IP	900	2700	FQ	FQ	FQ	N	FQ	FQ
	Copilot	500	650	FQ	FQ	FQ	N	FQ	FQ
	I B/O	1600	--	--	--	--	--	--	--
2-Grandforks	AC	880	940	FQ	FQ	FQ	FQ	FQ	FQ
	Copilot	1150	1220	FQ	FQ	FQ	FQ	FQ	FQ
	B/O	380	--	--	--	--	--	--	--
3-Pease	IP	2200	2200	FQ	FQ	FQ	FM	FQ	FQ
	Copilot	710	810	FQ	FQ	FQ	N	FQ	FQ
	I B/O	2060	--	--	--	--	--	--	--
4-Grissom	AC	1000	1060	FQ	FQ	T	T	T	FQ
	Copilot	750	850	FQ	FQ	T	FQ	FQ	FQ
	I B/O	2600	--	--	--	--	--	--	--
5-Beale	AC	1300	1300	FQ	FQ	FQ	FM	FQ	FQ
	Copilot	1400	1500	FQ	FQ	FQ	FQ	FQ	FQ
	B/O	1150	--	--	--	--	--	--	--
6-Minot	AC	1250	1290	FM	FQ	FQ	FM	FQ	FQ
	Copilot	650	850	FQ	FQ	FQ	FQ	FQ	FQ
	B/O	450	--	--	--	--	--	--	--
7-Fairchild	AC	1000	3165	FQ	FQ	FQ	FQ	FQ	FQ
	Copilot	80	80	N	FM	FQ	N	N	FQ
	B/O	420	--	--	--	--	--	--	--
8-McGhee Tyson	IP	500	7500	FQ	FQ	FQ	N	FQ	FQ
	IP	4600	6523	T	FQ	FQ	FQ	FQ	FQ
	I B/O	500	4000	--	--	--	--	--	--
9-Plattsburg	AC	1100	1100	FQ	FQ	FQ	FQ	FQ	FQ
	Copilot	800	800	FQ	FQ	FQ	FM	FQ	FQ
	B/O	385	--	--	--	--	--	--	--

IP - Instructor Pilot
AC - Aircraft Commander
B/O - Boom Operator
I B/O - Instructor Boom Operator

N - No experience
FM - Familiar only
T - Trained but not qualified
FQ - Fully qualified

*Since pilot training

FIGHTER DEPLOYMENT SUPPORT-LORING TANKER FORCE

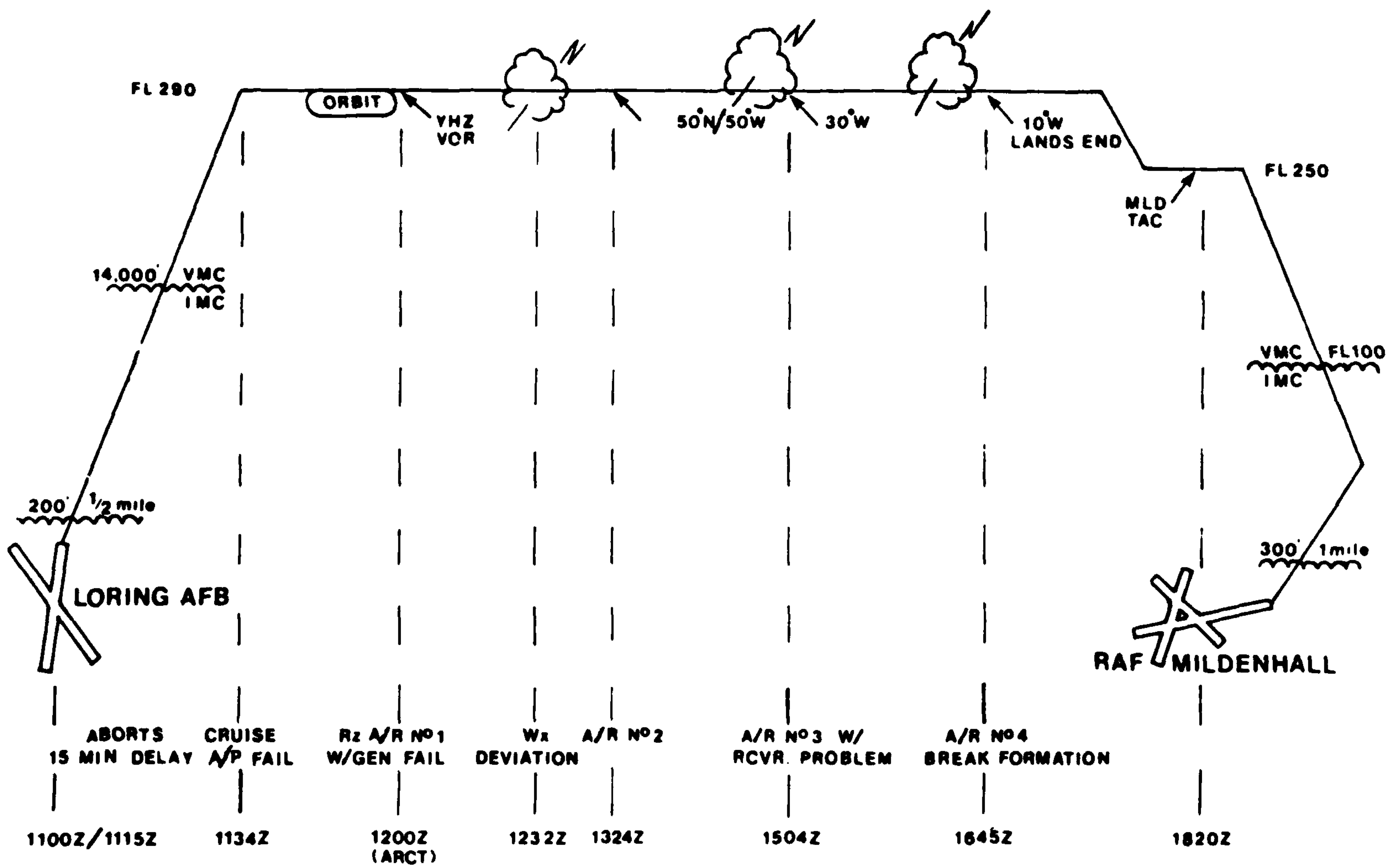


Figure 1

who are supporting the Coronet Eagle deployment of 12 A-7 receivers (call sign, Hotel Sierra 1-12). Esso 1 and 2 will deploy to Mildenhall, while the other three tankers return to Loring after offloading fuel to the receivers.

Prior to departing the briefing area, Esso Lead pilot conducts a pre-mission briefing with other cell aircrews covering communications, taxi, takeoff, climb, level off, join-up, formation tactics, offloads, and ARCTs - #1) 1200Z, #2) 1324Z, #3) 1504Z, #4) 1645Z. Weather and emergency procedures are also covered.

The boom operator departs to coordinate for inflight meals while pilots review and complete flight planning forms, charts and maps. Subsequently, the crew of Esso 2 loads all required equipment on the crew bus and departs base ops at 0935Z. At 0940Z, the Coronet tanker crews arrive at their respective aircraft for preflight and final crew briefings. Esso 2 experiences water failure on takeoff, aborts, returns to the hammerhead to check the system, which checks out satisfactorily. The remainder of the formation departs on schedule and Esso 2 departs 15 minutes behind the leader. A routine IMC departure is made with weather at 200' and 1/2 mile. After airborne a change of flight plan is requested to shorten the route so as to rendezvous with the tanker cell over the ARCP at Halifax (YHZ) at 1152Z prior to the scheduled rendezvous with the receivers. During level off at FL290 the aileron axis of the autopilot fails and cannot be revived. For this reason, after rendezvous, Esso 2 joins the cell in the #5 position. During tanker join-up at Halifax, Esso 2 experiences a generator failure which is resolved. Esso Lead and 2 refueling systems are checked by providing a token offload to one receiver each.

After the non-deploying tankers have twice refueled the fighters, they return to Loring and Esso 2 moves into the #2 position. Esso Lead radar becomes inoperative so Esso 2 assumes responsibility for formation station-keeping and weather avoidance through an extended area where numerous diversions around weather cells are required. At 30° W, halfway across the Atlantic, a third A/R is accomplished except for Hotel Sierra 12. After several unsuccessful attempts to refuel and tow, Hotel Sierra 12, accompanied by Hotel Sierra 11, heads for the closest landfall/airport - Shannon, Ireland with a projected flame out 40 miles short of the airfield. Esso 2 coordinates the problem with Head Dancer and rescue and proceeds with the remainder of the Coronet Eagle Contingent to the U.K. The fighters top off near Lands End and subsequently break away from the tanker cell to recover at RAF Wittering. The disabled receiver and escort are assisted to Shannon by Head Dancer and Duckbutt. Esso 2 accomplished a minimum weather recovery at RAF Mildenhall at 1820Z.

MILDENHALL EWO MISSION
(LEG 2)
(Figure 2)

After arrival at RAF Mildenhall, the KC-135 crew has completed their crew rest and are now on alert in the alert facility. Nuclear war appears imminent. The following is a mission scenario for KC-135A, call sign Filip 66. The mission kit shows this aircraft as number 2 in a two ship cell of KC-135s. The takeoff will be from RAF Mildenhall to a rendezvous with two B-52s coming easterly from the United States. The rendezvous point is in a high latitude area at N73°00'W001°00'. The ARCT will be 0130Z.

The fuel offload will be 100,000 pounds per each KC-135 with a recovery in northern Norway. The lead KC-135, Filip 61, will be responsible for the navigation and communication enroute. Filip 66 will follow in formation using airborne radar to keep his relative position (station keeping) from the lead aircraft. The crew will navigate and monitor communications as a backup. The crew has studied the mission and completed the necessary flight planning. The aircraft is cocked. The proposed flight plan and the aircraft's position on the alert pad have been stored in the navigation management system, however, the INS gyros are not aligned.

As an overview to this portion of the mission scenario, hostilities have broken out between Communist block countries and friendly nations. As a result, the SAC alert force has launched and is proceeding toward target areas. The two ship cell of KC-135s depart RAF Mildenhall at 2200Z, nighttime, with a 3,000 foot ceiling and 7 nautical miles visibility. They climb to FL290 and FL295 respectively, and proceed in IMC conditions by normal navigation and station keeping procedures direct to an overwater, high latitude rendezvous with their two B-52 receivers. Approximately four hundred miles prior to the ARCP, the lead KC-135 experiences an uncontrollable engine fire. That aircraft leaves the formation and sets course toward an emergency recovery base, while Filip 66 proceeds. When approaching the ARCP, several severe thunderstorms with tops estimated at above FL400 are detected in the planned refueling track by Filip 66 and the two B-52 receivers, Bozo 21 and Bozo 24. A new refueling track clear of the thunderstorms is plotted and coordinated between aircraft. Authentications are completed and a diversion is made to the new refueling track. A point parallel rendezvous is completed. Filip 66 refuels both Bozo 21 and 24, since the other tanker is not available. Filip 66, with only emergency fuel, recovers at the nearest airfield, Bodo, Norway. Ground navigation aids have been shut down or jammed so an airborne radar approach (ARA) is made with only enough fuel for one approach. The weather at Bodo is a 400 foot ceiling and 1 NM

MILDENHALL EWO MISSION

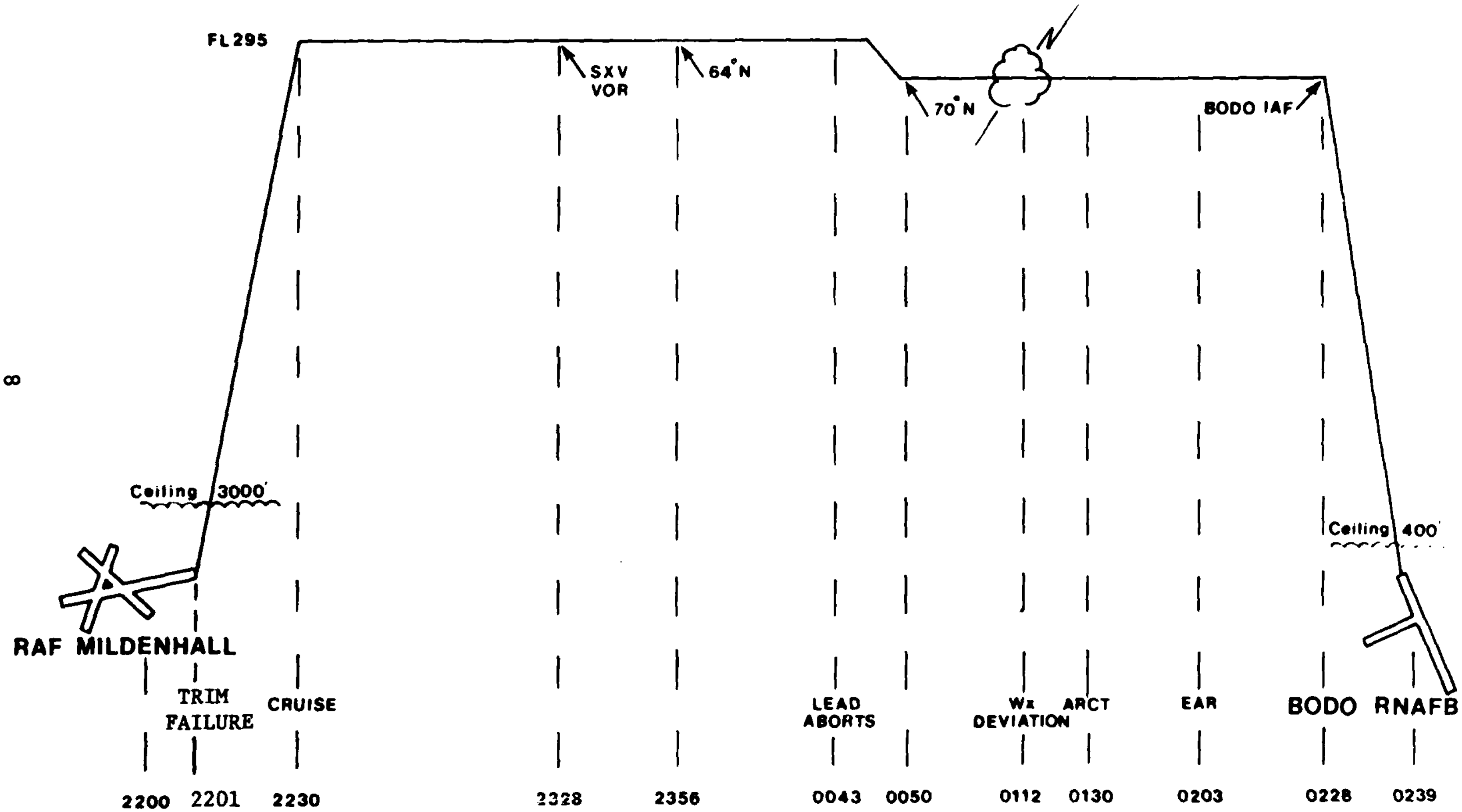


Figure 2

visibility in nighttime conditions. The mission is further complicated by a runaway stabilizer trim at liftoff, the tanker's rendezvous beacon being inoperative, smoke and fumes from the air conditioning system being detected during the aerial refueling of the B-52s and two engines flaming out from fuel starvation on final approach prior to a successful recovery at Bodo, Norway.

BODO CONTINGENCY MISSION
(LEG 3)
(Figure 3)

The KC-135 has been towed off the taxiway at Bodo, maintenance discrepancies have been corrected, and it has been refueled with 120,000 pounds of fuel. A thru-flight inspection has been performed by the crew chief. The pilots proceeded to operations where they contacted their operation center through NATO land line communications. They reported Filip 61's emergency, his unknown disposition and the amount of fuel offloaded to each of Bozo 21 and 24. They were directed by their operaton center to relaunch as lead in a two ship cell with TACO 33, another KC-135 which recovered at Bodo. TACO 33 has an inoperative navigation management system. They are to proceed to an anchor point over the Baltic Sea at N58°40", E19°40" to refuel multiple flights of fighter aircraft striking targets in Western Eurasia. The air refueling control time (ARCT) is 0852Z. The tankers' altitudes in the anchor will be FL290 and FL300. The receivers will be vectored by GCI Control. Filip 66 and TACO 33 are to remain in the refueling track until they have only enough fuel remaining to safely recover at Aalborg Royal Danish Air Force Base, Denmark.

The crew obtains an intelligence briefing from NATO Ops. NATO is involved in a limited war with the Soviet block nations. Aircraft are operating on tactical clearances without air traffic control clearances. Some control towers and military radars are operating. All navigation aids have been shut down, and jamming and interference is taking place on all communication radios. Nuclear detonations are possible. Crews are advised to wear gold goggles. Enemy fighter aircraft have been reported infringing upon free airspace from both ground bases and aircraft carriers.

Mission and crew briefings are completed. The crew inserts the proposed flight plan into the nav management system. The inertial navigation systems are aligned prior to taxiing. As Lead they make a two ship, day, IMC departure with ceiling at 400 feet and visibility at 1 NM. The aircraft climb to FL290 and FL295 respectively, and proceed to the anchor point, where the pattern is established prior to the control time. TACO 33 climbs to FL300. Enroute to the ARCP, an electrical system malfunction occurs and subsequently

BODO CONTINGENCY MISSION

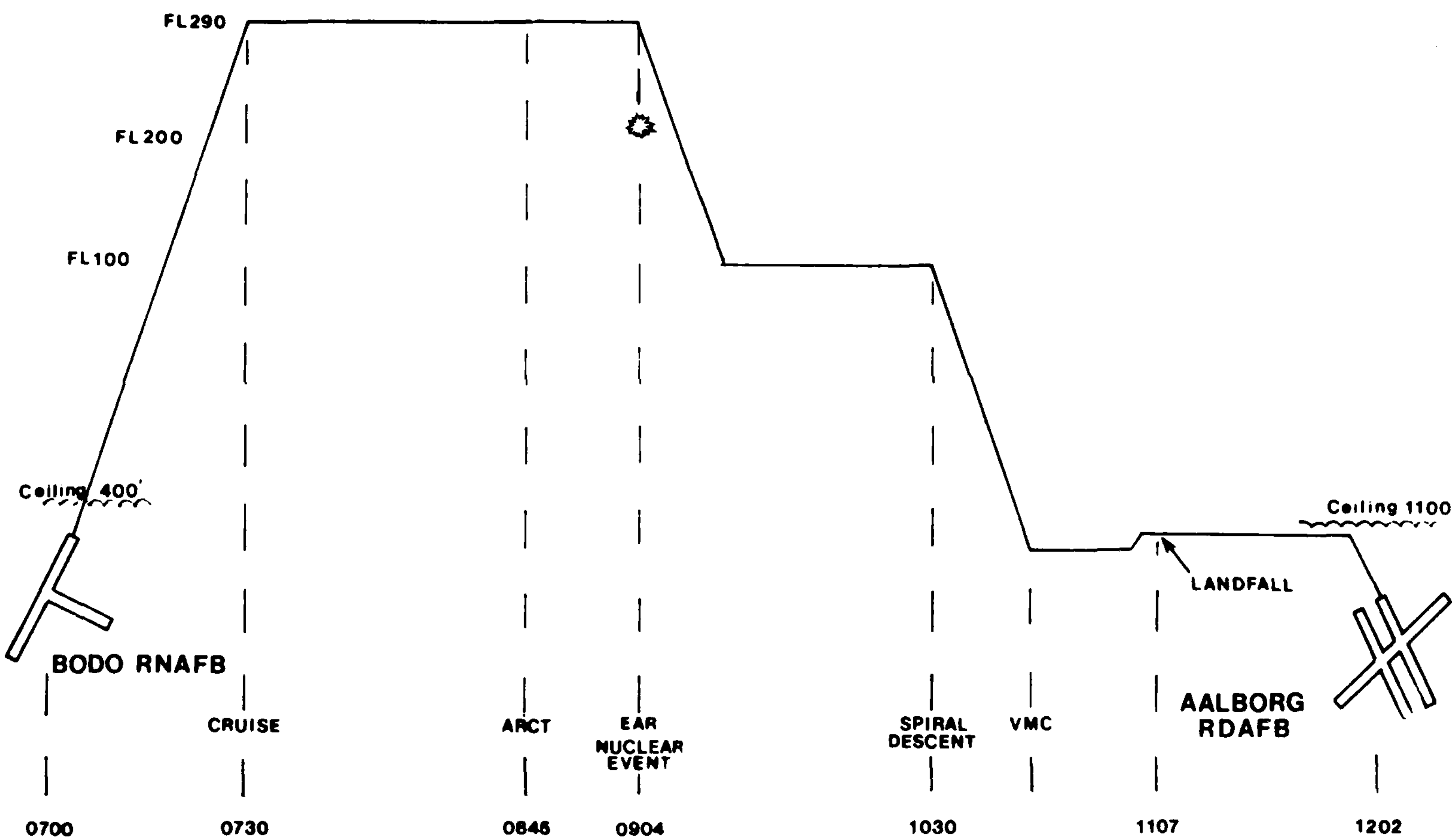


Figure 3

the pilot's nav management system control/display unit (CDU) becomes inoperative, requiring all further navigation interface to be conducted through the copilot's CDU. GCI assistance is not available until after the aircraft are in the anchor.

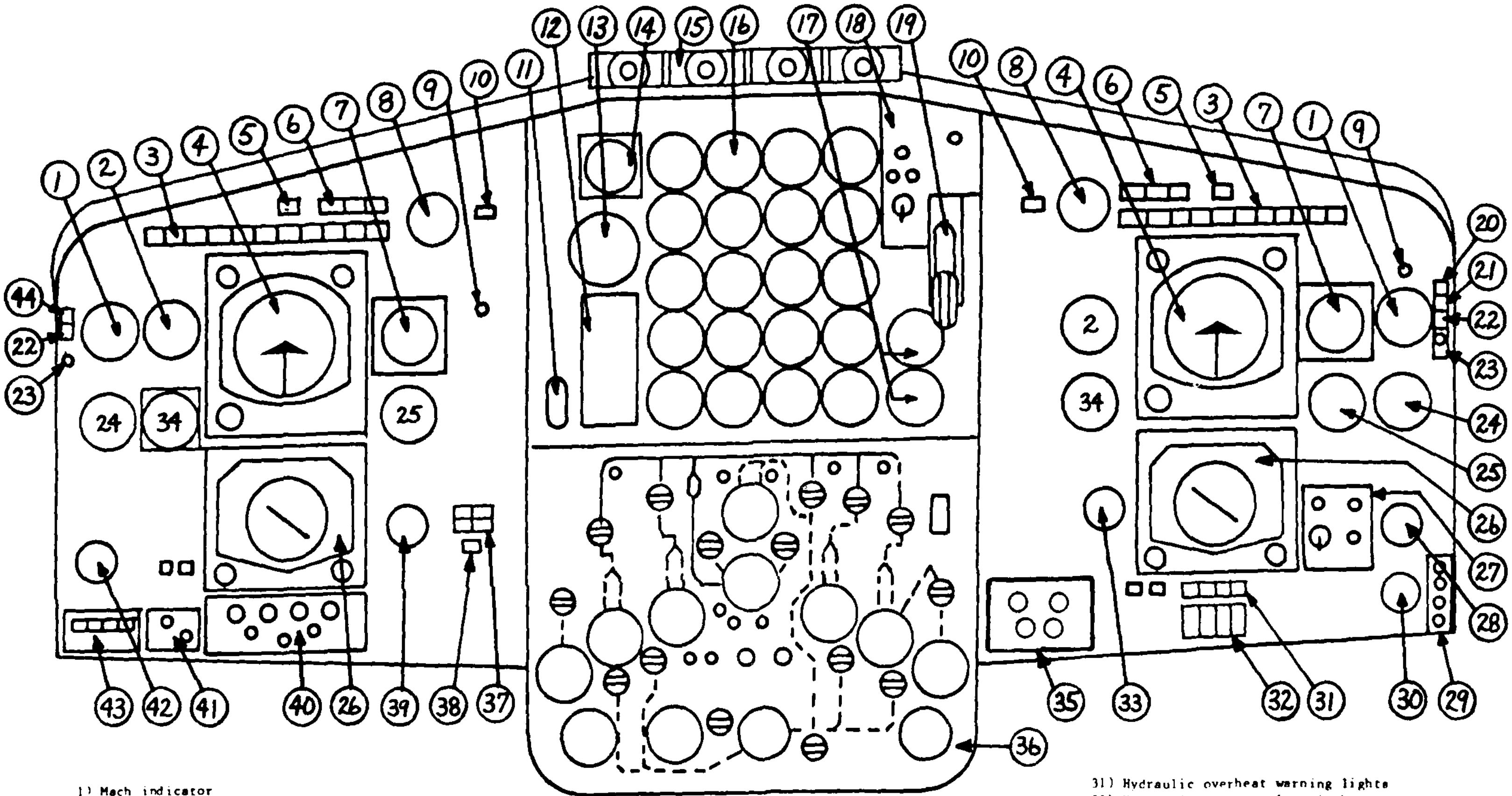
GCI vectors numerous F-15, F-16, A-7, and F-4 aircraft, formations and single ships, in for refueling from both tankers. Fighters are both inbound to and outbound from target areas. Some are required to hold out while others are on the tanker. Some are extremely low on fuel, requiring coordination for priority treatment. In one case the tanker is required to cut short the anchor and proceed toward a point in the anchor pattern closer to an emergency fuel fighter. The pattern is also complicated by several weather cells which must be circumnavigated along one side of the anchor.

After approximately 1 1/2 hours in the pattern, enemy fighters attack the formation. A nuclear device is detonated and Filip 66 is subject to an electro-magnetic pulse (EMP). The loss of all non-hardened avionics systems ensues, leaving Filip 66 without communications and with only limited flight instruments and navigational capability. Most electrically operated controls and indicators are inoperative. The boom operator, in the boom pod without his goggles, is blinded by the flash. Filip 66 unable to see or communicate with TACO 33, turns southwestward, dead reckons to a position believed to be over the North Sea and makes a slow spiraling descent to VMC conditions over the water. He then turns northeast and proceeds until landfall on the northwest coast of Denmark. Using dead reckoning he proceeds visually to Aalborg Royal Danish Air Force Base. A visual approach is made to Aalborg with the ceiling at 1,100 feet and the visibility at 3 miles. The landing gear and wing flaps are extended normally and a successful landing concludes this portion of the mission.

Crew Station Designs. Three cockpit configurations were evaluated during the mockup exercise -- the minimum update, the moderate update, and the major update. This section describes the changes made from the current KC-135 and the rationale behind those changes.

Mimimum Update

The minimum update is the least "sophisticated" of the three designs and basically involves the moving forward of all the navigator station controls and displays that the pilots would have to operate and/or reference during flight. No changes are made to the pilot's or copilot's front instrument panels (Figure 4) except that an INS select switch (item 10) is added to both panels which enables the INS signal to be coupled to the HSI (item 26). There are also no changes made to the fuel panel (item 36). On the



1) Mach indicator
2) Airspeed indicator
3) FD-109/RGA system annunciators
4) Attitude director indicator
5) Comparator warning switch annunciator
6) Attitude warning indicators
7) Altimeter
8) Angle of attack indicator
9) Marker beacon light
10) TACAN/INS select switch

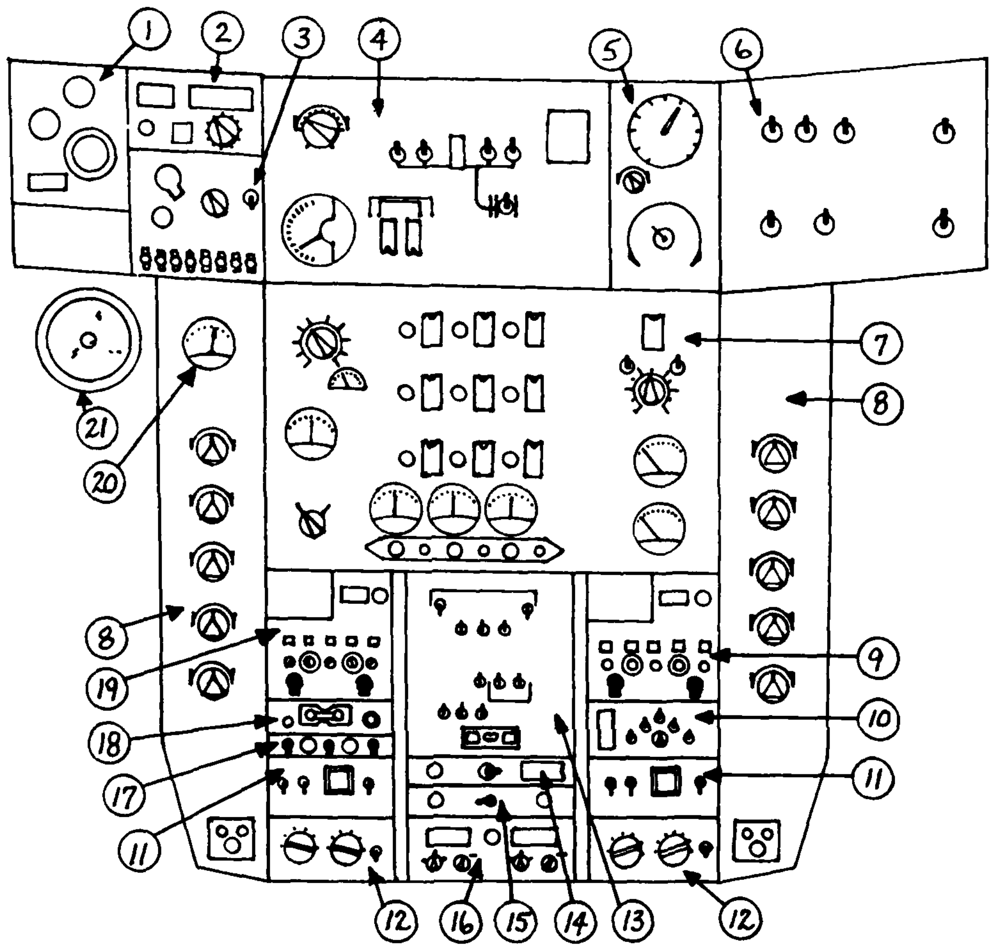
New hardware, current tanker location
* Current tanker hardware, new location

11) Cabin pressure emergency release
12) Battery power panel
* 13) True airspeed indicator
14) Accelerometer
15) Engine fire switches
16) Engine instruments
17) Flap position indicators
18) Landing gear panel
19) Landing gear lever
20) Cargo door/hatch not latched warning light

21) Cabin pressure warning light
22) RGA fail operative light
23) FD-109/RGA power-off light
24) Radio magnetic indicator
25) Vertical velocity indicator
26) Horizontal situation indicator
27) Copilot instrument power panel
28) Cabin altimeter
29) Hydraulic pump inoperative lights
30) Hydraulic oil quantity gauge

31) Hydraulic overheat warning lights
32) Hydraulic pump supply switches
33) Hydraulic pump supply
34) Radio altimeter
35) Water injection control panel
36) Fuel control panel
37) Engine oil low pressure warning lights
38) Boom engaged light
39) Clock
40) Engine ignition and start panel
41) Pilot instrument gyros switches
42) Rudder power hydraulic pressure gauge
43) Comparator warning monitor panel
44) Autopilot disengaged light

Figure 4. Minimum Update: Pilot/Copilot Front Instrument Panels and Forward Center Console

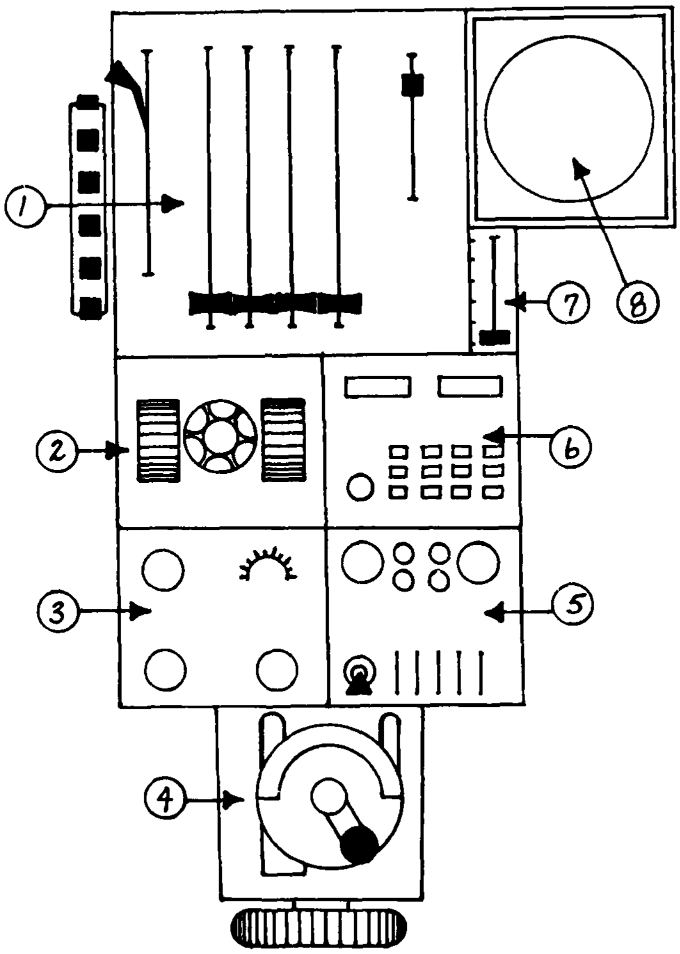


* 1) Radar pressurization panel
* 2) Doppler control panel
* 3) APN-69 beacon panel
4) Air-conditioning control panel
5) Cabin pressure controllers
6) Light control panel (exterior)
7) Electrical control panel
8) Light control panel (interior)
9) UHF #2 comm control panel
10) Ciphony control panel

11) Rotation go-around control panel
12) Flight director control panel
13) Autopilot control panel
14) Warning bell control panel
15) Dual remote heading slew switch
16) VHF #1 and #2 navigation control panel
17) Loudspeaker and TACAN antenna control panel
18) TACAN control panel
19) UHF #1 comm control panel
20) Battery charging ammeter
21) Speaker

* Current tanker hardware, new location

Figure 5. Minimum Update: Overhead Panel



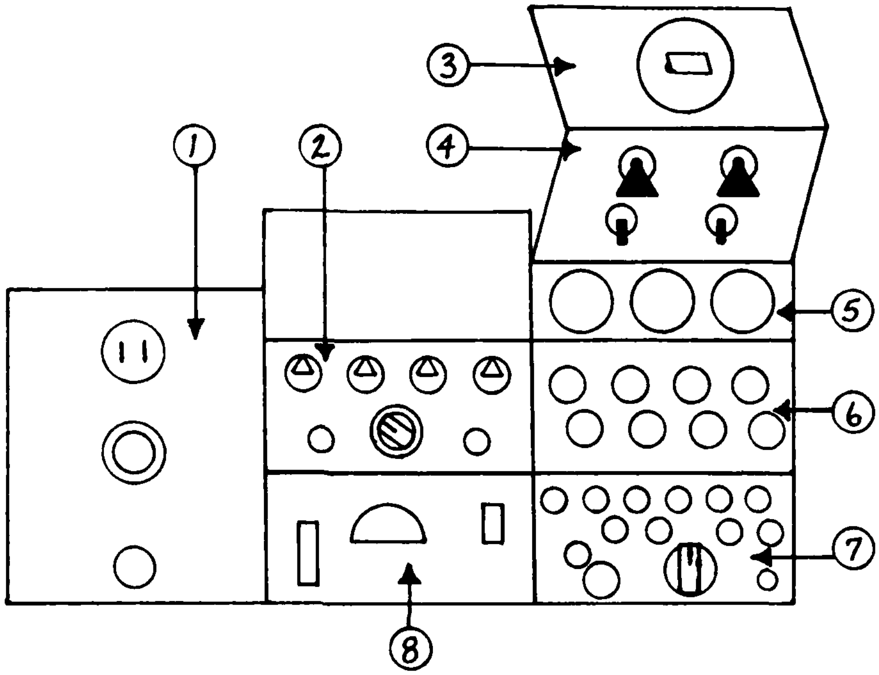
1) Throttle quadrant (standard)
* 2) Autopilot controller
+ 3) Radar control panel
4) Rudder and aileron trim

* 5) IFF control panel
+ 6) Inertial navigation system
7) Wing flap handle (modified)
8) Radar scope

NOTE: Inertial Navigation System No. 2 located at standard Navigator's panel

+ New hardware, new location
* Current tanker hardware, new location

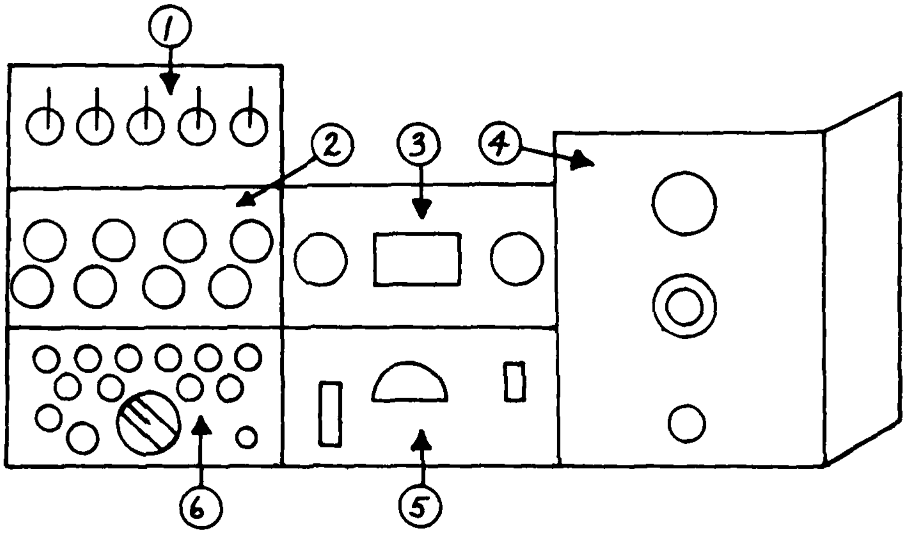
Figure 6. Minimum Update: Aft Center Console



1) Light dimmer, oxygen hose, electrical receptacle
* 2) HF comm control panel
3) Ash tray
4) Hydraulic control panel
5) Hydraulic pressure indicators
6) Nav monitor panel
7) AIC-18
8) Oxygen regulator

New hardware, current tanker location
* Current tanker hardware, new location

Figure 7. Minimum Update: Pilot Side Panel



1) Windshield anti-ice
\# 2) Nav monitor panel
\+ 3) VHF comm control panel
4) Electrical receptacle, oxygen hose, light dimmer
\# 5) Oxygen regulator
\# 6) AIC-18

\+ New hardware, new location
\# New hardware, current tanker location

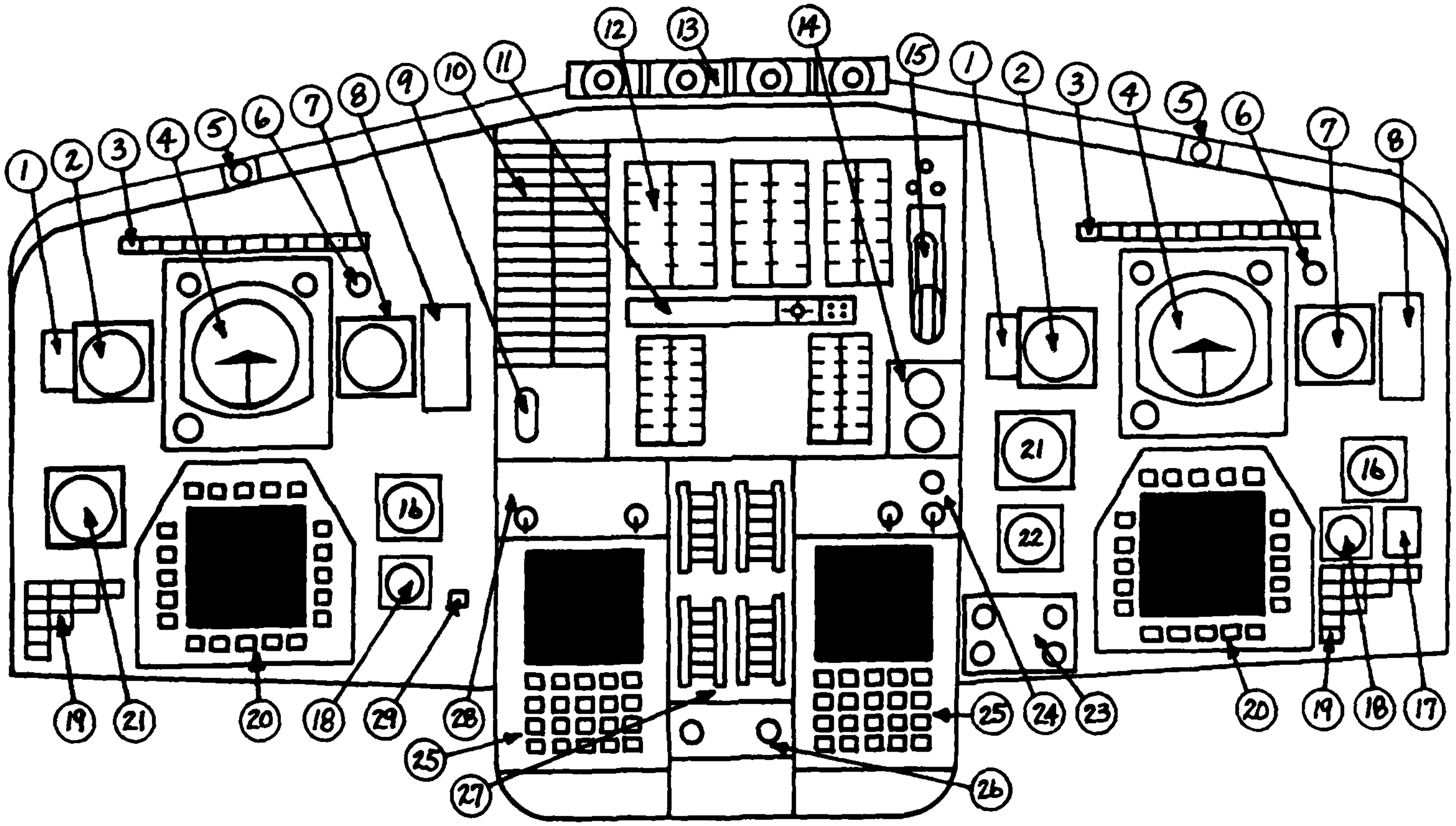
Figure 8. Minimum Update: Copilot Side Panel

center instrument panel (Figure 4) a true airspeed (TAS) indicator (item 13) is added. On the overhead panel (Figure 5), an APN-69 rendezvous beacon (item 3), radar pressurization panel (item 1), and doppler control (item 2) are added. The aft center console (Figure 6) is widened aft of the throttle quadrant (item 1) and the flap control (item 7) is made smaller and is moved slightly forward. An INS control/display unit (CDU) is added (item 6), as are IFF (item 5) and radar controls (item 3). The pilot's side panel (Figure 7) replaces the AIC-10 with an AIC-18 (item 7) and adds an HF comm control head (item 2). The copilot's side panel (Figure 8) also has the AIC-10 replaced with an AIC-18 (item 6) and has a VHF comm head added (item 3) while the HF comm head and IFF ident control are removed. The addition of an INS ON/ALIGN control (not pictured) completes the changes to the copilot's side panel. Finally, a performance scroll (not pictured) is added to the glare shield and let-down plate holders (not pictured) are added to the pilot's and copilot's side window. The AIC-10 on the FD-109 equipment rack is replaced by an AIC-18 and is used by the boom operator.

In the moderate update, all controls are consolidated within the reach of both pilots and most of them are also within the reach of the boom operator, since it is difficult to predict when one or more crew members may become overloaded. Additionally, all controls and displays for similar systems are grouped together and certain systems are integrated so that a mission computer can do most of the calculations and other "busywork" tasks. The rationale behind the major update is the same as this except that, in addition, certain systems are more automated to further reduce workload. Because many systems/changes are identical in both the moderate and major designs, these are described first for both systems.

Common Changes To The Moderate And Major Updates

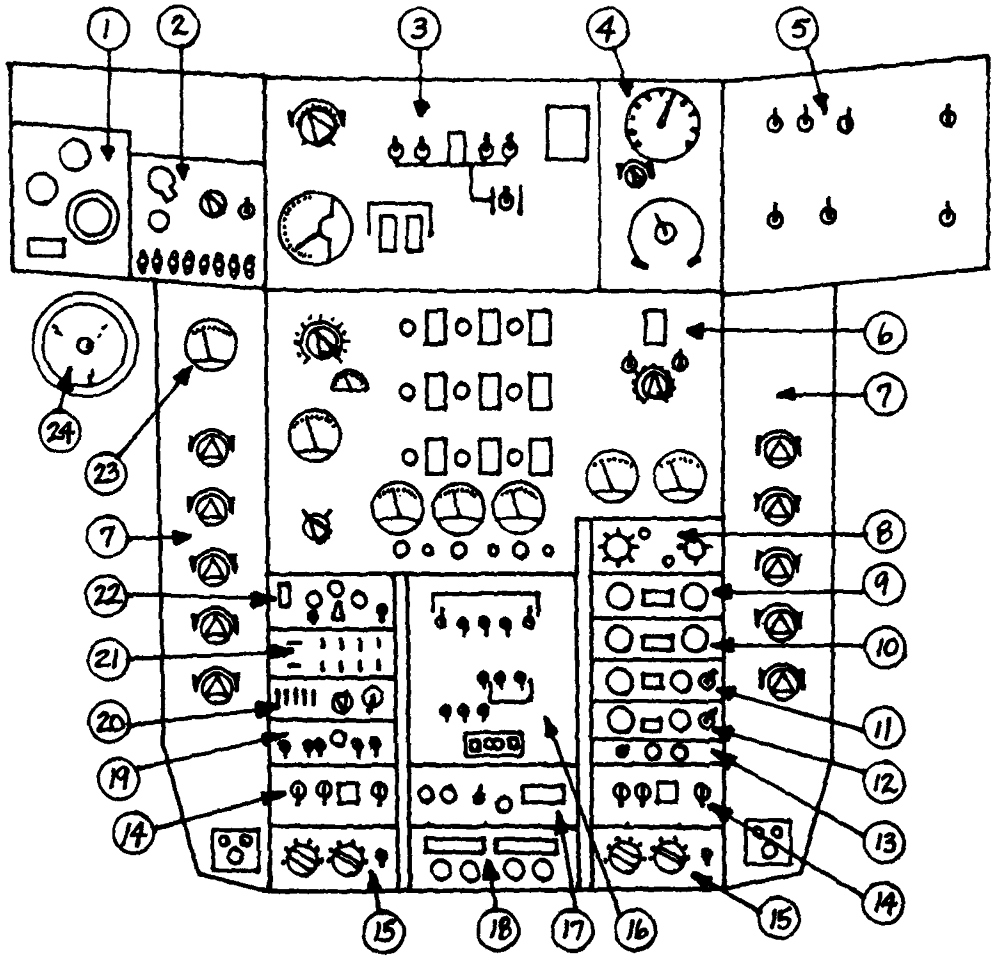
The pilot's and copilot's instrument panels in both the moderate (Figure 9) and major (Figure 14) updates have the addition of an F-16 vertical scale scale angle of attack (item 1), the combination of the mach and airspeed indicators into one instrument (item 2) and the addition of a vertical scale radio altimeter (item 8). These changes are made in the interest of saving space on the panels. A CRT horizontal situation display (Figure 9, item 20; Figure 14, item 21) with navigation mode and display format selection switches (Figure 9, item 19; Figure 14, item 20) replaces the standard HSI, and a bearing-distance-heading indicator (Figure 9, item 21; Figure 14, item 22) replaces the standard RMI in both updates. In addition, a clock (Figure 9, item 18; Figure 14, item 19) and marker beacon light (Figure 9, item 6; Figure 14, item 9) are added to the copilot's front panel. On the center instrument panel of both designs, vertical scale, segmented-light engine, pressure, and quantity instruments are included (Figure 9, item 12; Figure 14, item 14). Selectable digital readouts of those parameters are provided. The accelerometer is removed from the aircraft.



- ♦ 1) Angle of attack indicator
- ♦ 2) Mach/airspeed indicator
- 3) FD-109 system annunciator lights
- 4) Attitude director indicator
- ♦ 5) Master caution light
- 6) Marker beacon light
- 7) Altimeter
- ♦ 8) Radio altimeter
- 9) Cabin pressure emergency release
- ♦ 10) Caution/warning annunciator panel
- ♦ 11) Engine instrument digital readouts and selector
- ♯ 12) Engine instruments
- 13) Engine fire switches
- 14) Flap position indicators
- 15) Landing gear lever
- 16) Vertical velocity indicator
- 17) Cabin pressure gauge
- 18) Clock (also added for copilot)
- ♦ 19) Navigation and horizontal situation display mode selector switch
- 20) HSD/MPD
- ♦ 21) Bearing-distance-heading indicator (BDHI)
- 22) Outside air temperature gauge
- 23) Water injection control panel
- ♦ 24) Radar cursor control panel
- ♦ 25) Nav management control/display unit
- ♦ 26) Doppler on-off switch
- ♦ 27) Fuel quantity indicators
- ♦ 28) Inertial navigation system control panel
- 29) Boom engaged light

♦ New hardware, new location
♯ New hardware, current tanker location

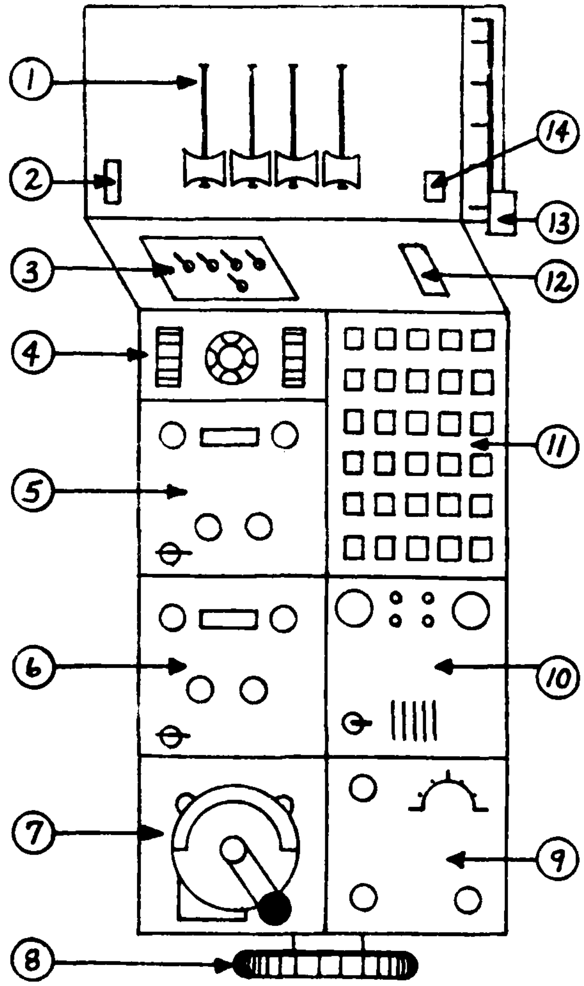
Figure 9. Moderate Update: Pilot/Copilot Front Instrument Panels and Forward Center Console



* 1) Radar pressurization panel
* 2) APN-69 beacon panel
3) Air-conditioning control panel
4) Cabin pressure controllers
5) Light control panel (exterior)
6) Electrical control panel (modified)
7) Light control panel (interior)
\+ 8) Attitude heading reference system (AHRS)
* 9) HF comm control panel
\+ 10) VHF comm control panel
* 11) TACAN #1 control panel
\+ 12) TACAN #2 control panel
* 13) Loud speaker and TACAN antenna control panel
14) Rotation go-around control panel
15) Flight director control panel
16) Autopilot control panel
17) Warning bell control and remote heading slew switch
18) VHF #1 and #2 navigation control panel
\+ 19) Anti-ice control panel
\+ 20) Instrument power control panel
\+ 21) Hydraulic control panel
* 22) Ciphony control panel
23) Battery charging ammeter
24) Speaker

\+ New hardware, new location
* Current tanker hardware, new location

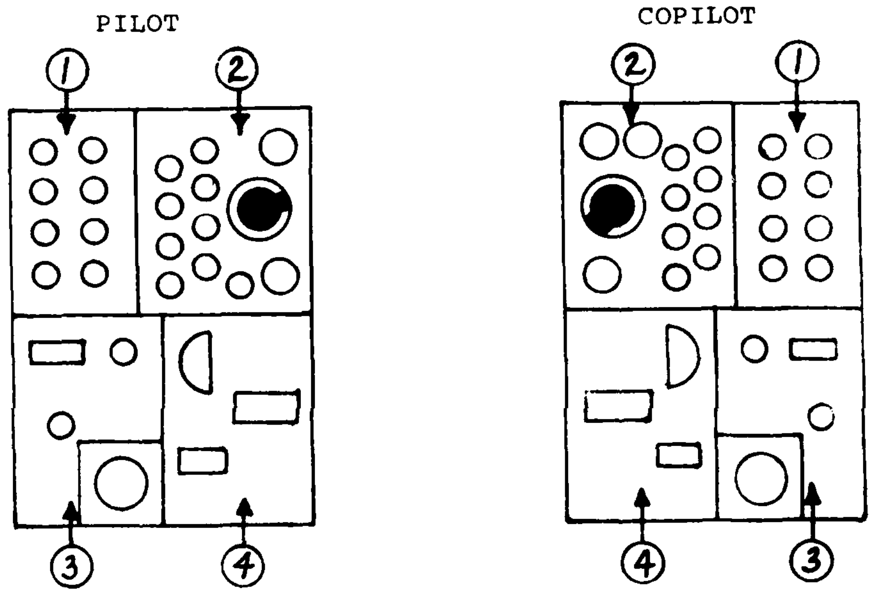
Figure 10. Moderate Update: Overhead Panel



	1) Throttle quadrant	*	8) Aileron trim
*	2) Rudder power switch	+	9) Radar control panel
*	3) Engine start panel	*	10) IFF/SIF control panel
*	4) Autopilot controller	+	11) Fuel switching matrix and fuel dump
*	5) UHF #1 comm control panel	*	12) Gear horn switch
*	6) UHF #2 comm control panel	*	13) Wing flap control
*	7) Rudder trim		14) Stab trim cut out switch

+ New hardware, new location
* Current tanker hardware, new location

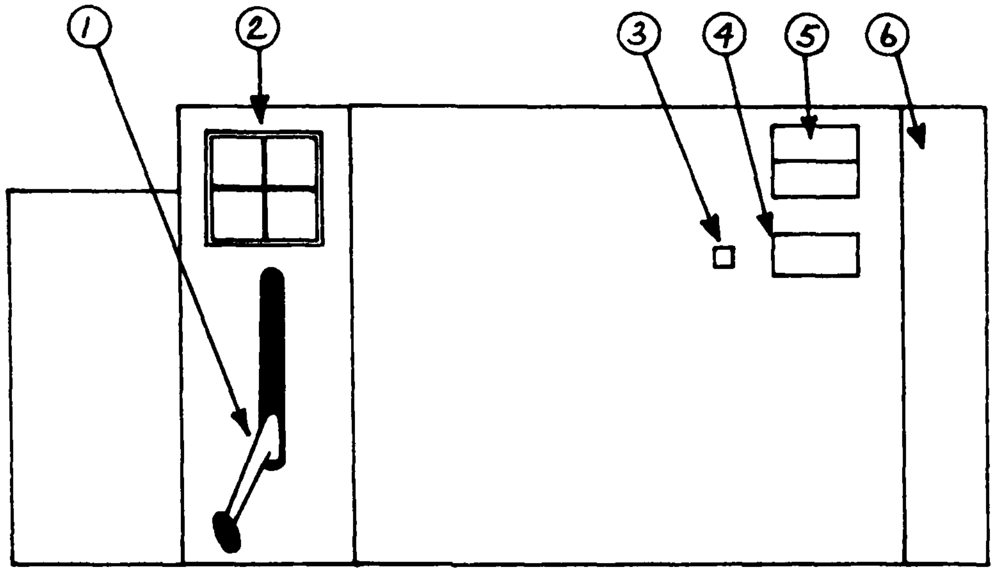
Figure 11. Moderate Update: Aft Center Console



\# 1) Nav monitor panel
\# 2) AIC-18
* 3) Oxygen hose, dimmer, oxygen quantity, lamp receptacle
\# 4) Oxygen regulator

\# New hardware, current tanker location
* Current tanker hardware, new location

Figure 12. Moderate Update: Pilot/Copilot Side Panels

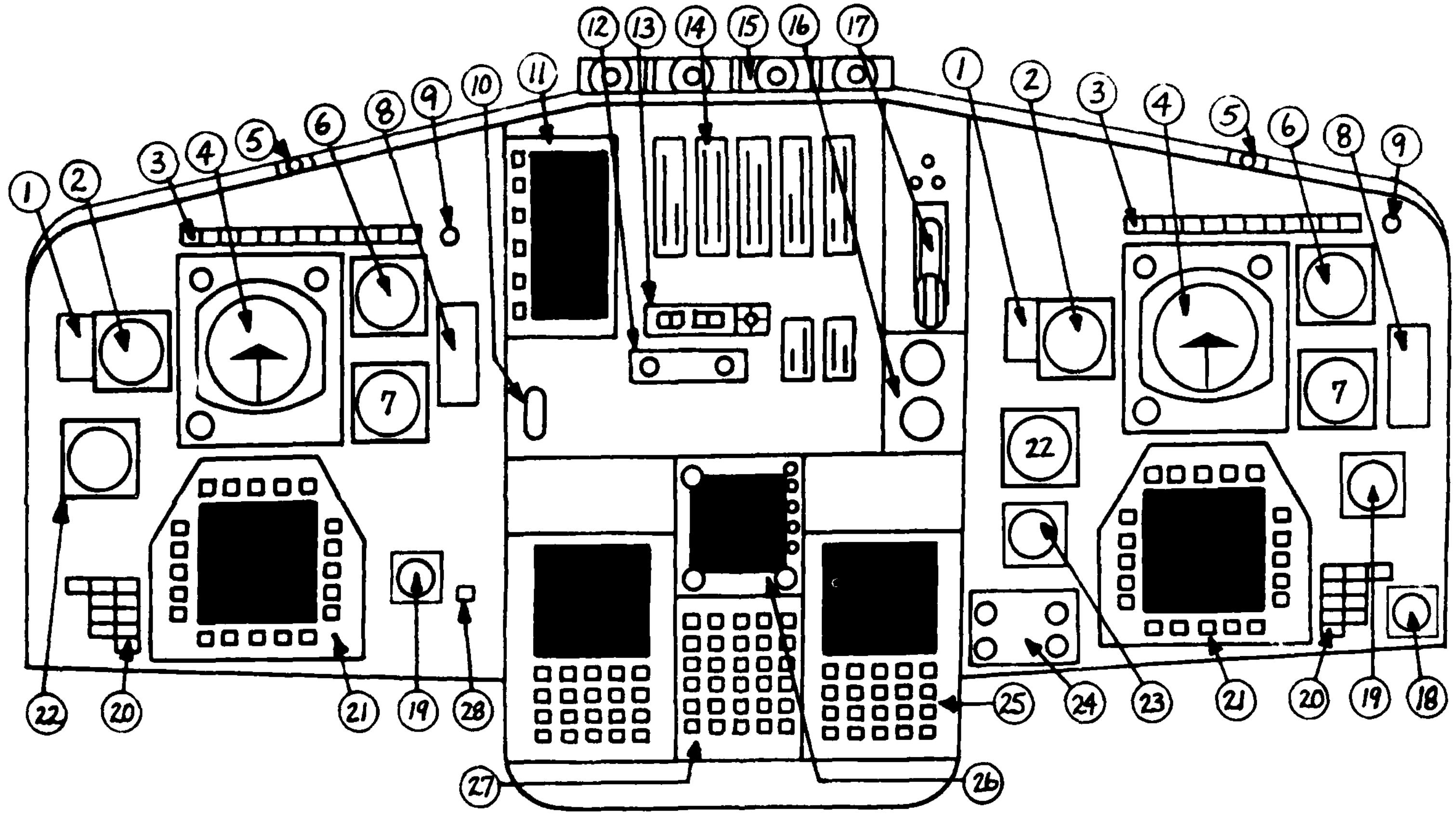


1. Boom Telescope Lever
2. Air Refuel Pump Switches
3. Air Refuel Master
4. Aircraft Total Fuel Quantity Indicator
5. Transfer Flow Rate and Totalizer
6. Light Control Switches

Boom Operator Control Panel Modified Only as Follows:

1. Move A/R master slightly to left
2. Add transfer fuel flow rate and totalizer indication
3. Add aircraft total fuel quantity indicator
4. Replace boom operator and instructor boom operator AIC-10s with AIC-18 interphone panels
5. Add forward and aft A/R fuel pump switches

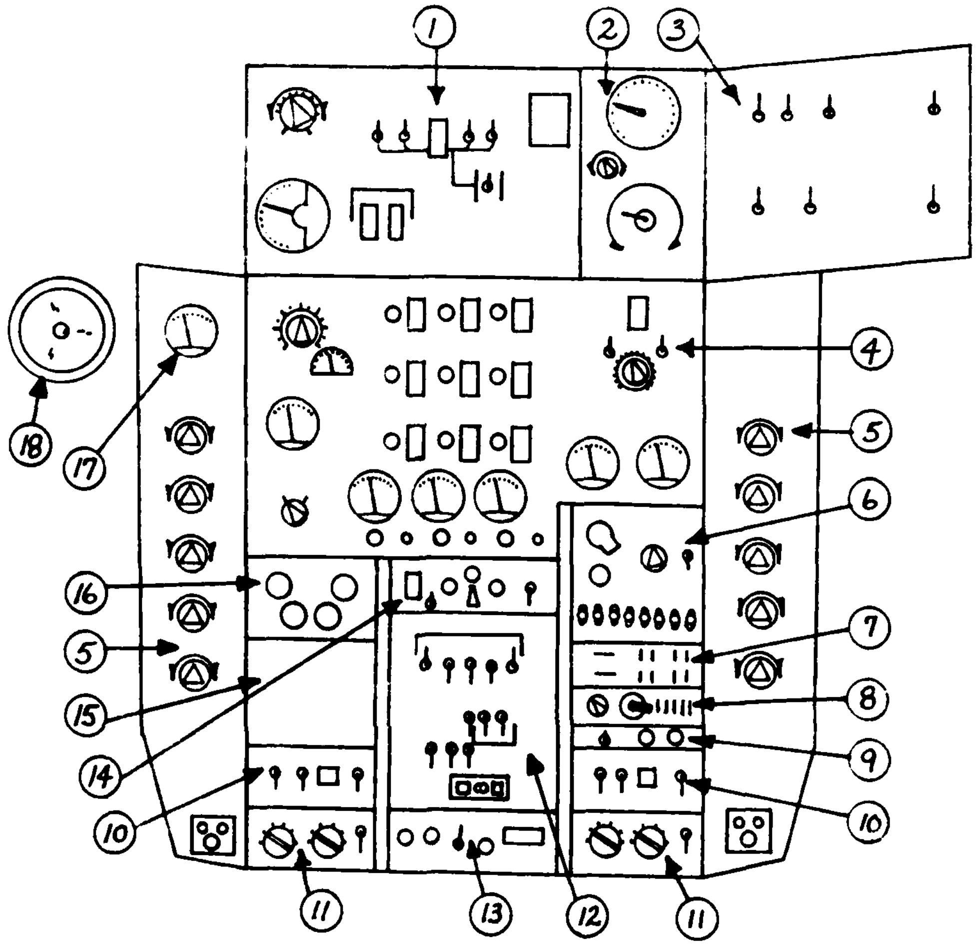
Figure 13. Moderate Update: Aft Boom Operator Station



• 1) Angle of attack indicator
• 2) Mach airspeed indicator
3) FD-109 system annunciator lights
4) Attitude director indicator
• 5) Master caution light
6) Altimeter
7) Vertical velocity indicator
• 8) Radio altimeter
9) Marker beacon light
10) Cabin pressure emergency release
• 11) Caution warning display
• 12) Attitude heading reference system control panel
• 13) Engine instruments digital readouts and selector
♦ 14) Engine instruments
15) Engine fire switches
16) Flap position indicators
17) Landing gear lever
18) Cabin pressure gauge
19) Clock (also added for copilot)
• 20) Navigation and horizontal situation display mode selector switches
♦ 21) HSD/MPD
• 22) Bearing-distance-heading indicator
23) Outside air temperature gauge
24) Water injection control panel
• 25) Nav management control/display unit
• 26) CRT multipurpose display
• 27) Fuel switching matrix
28) Boom engaged light

• New hardware, new location
♦ New hardware, current tanker location

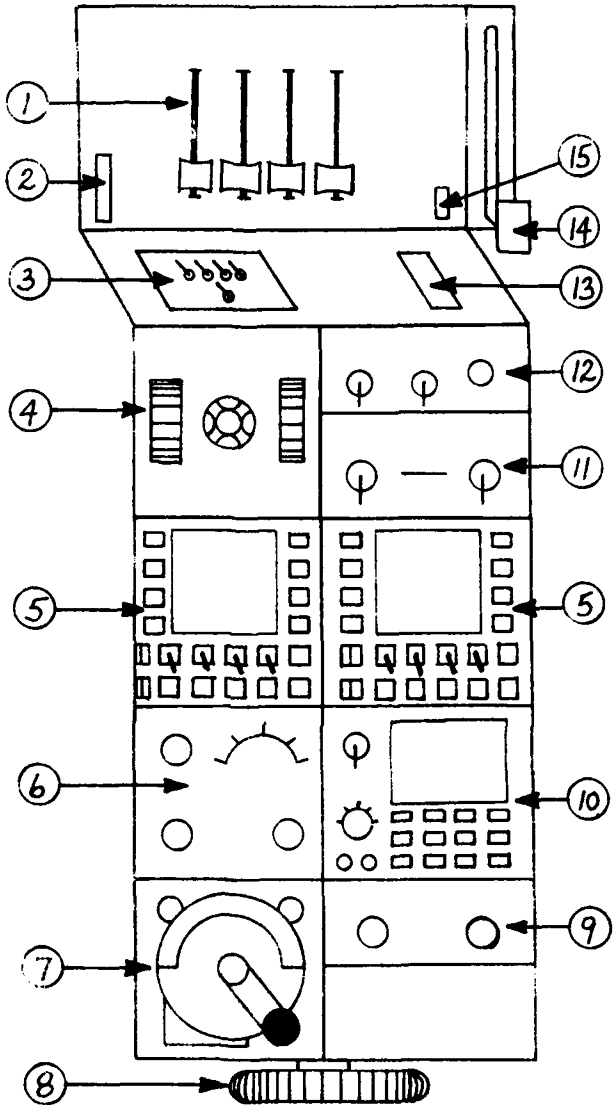
Figure 14. Major Update: Pilot/Copilot Front Instrument Panels and Forward Center Console



1) Air-conditioning control panel
2) Cabin pressure controllers
3) Light control panel (exterior)
4) Electrical control panel (modified)
5) Light control panel (interior)
* 6) APN-69 beacon panel
\+ 7) Hydraulic control panel
\+ 8) Instrument power control panel
* 9) Loudspeaker and TACAN antenna control panel
10) Rotation go-around control panel
11) Flight director control panel
* 12) Autopilot control panel
* 13) Warning bell control and remote heading slew switch
* 14) Ciphony control panel
15) Growth area
* 16) Radar pressurization panel
17) Battery charging ammeter
18) Speaker

\+ New hardware, new location
* Current tanker hardware, new location

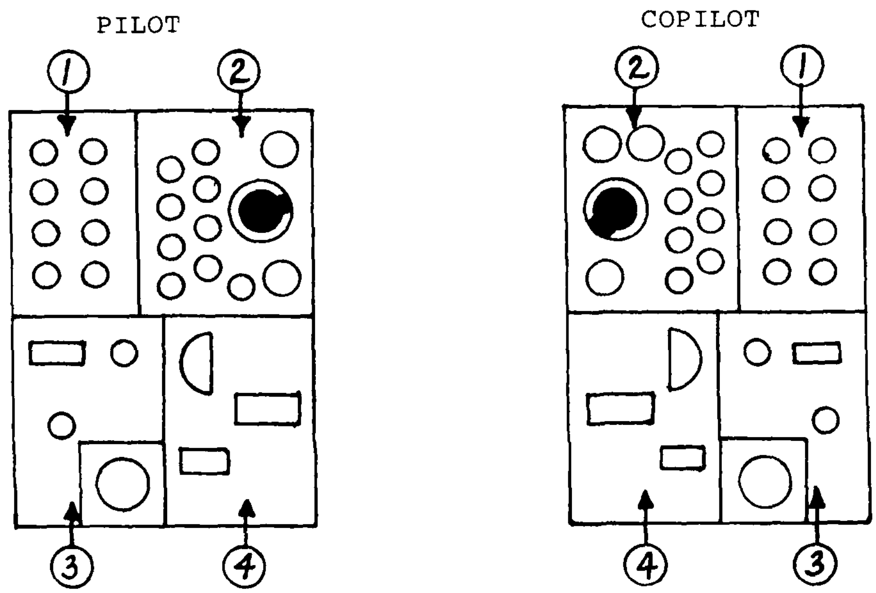
Figure 15. Major Update: Overhead Panel



1) Throttle quadrant
* 2) Rudder power switch
* 3) Engine start panel
* 4) Autopilot controller
+ 5) Comm-Nav/IFF tuning cockpit display unit
+ 6) Radar control panel
* 7) Rudder trim
* 8) Aileron trim
+ 9) Doppler on-off switch
+ 10) CRT multipurpose display (to include Fuel Management, CG, TOLD, & Checklists)
+ 11) Inertial navigation system control panel
+ 12) Radar cursor control
* 13) Gear horn switch
* 14) Wing flap controls
15) Stab trim cut out switch

+ New hardware, new location
* Current tanker hardware, new location

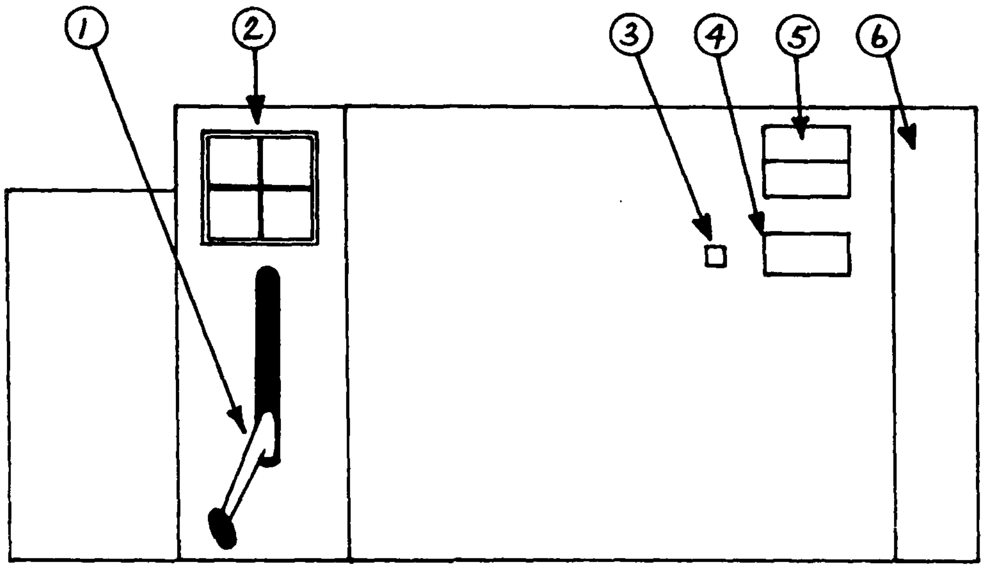
Figure 16. Major Update: Aft Center Console



1) Nav monitor panel
2) AIC-18
* 3) Oxygen hose, dimmer,
oxygen quantity,
lamp receptacle
4) Oxygen regulator

New hardware, current tanker location
* Current tanker hardware, new location

Figure 17. Major Update: Pilot/Copilot Side Panels



1. Boom Telescope Lever
2. Air Refuel Pump Switches
3. Air Refuel Master
4. Aircraft Total Fuel Quantity Indicator
5. Transfer Flow Rate and Totalizer
6. Light Control Switches

Boom Operator Control Panel Modified Only as Follows:

1. Move A/R master slightly to left
2. Add transfer fuel flow rate and totalizer indication
3. Add aircraft total fuel quantity indicator
4. Replace boom operator and instructor boom operator AIC-10s with AIC-18 interphone panels
5. Add forward and aft A/R fuel pump switches

Figure 18. Major Update: Aft Boom Operator Station

The overhead panel of both configurations has the following changes: the addition of a radar pressurization panel (Figure 10, item 1; Figure 15, item 16) and an APN-69 beacon control panel (Figure 10, item 2; Figure 15, item 6), while all anti-ice/de-ice switches, instrument power switches, and all hydraulic controls are consolidated on a panel where both pilots can reach them (Figure 10, items 19, 20, 21; Figure 15, items 7, 8). As a result of these switch/control groupings onto the overhead panel, most systems controls and displays are removed from the pilot's and copilot's side panels.

In the forward center console area of both the moderate (Figure 9) and major (Figure 14) updates, the fuel panel is removed and replaced by two navigation management control/display units (nav management CDUs) (item 25 in both figures) and other related controls and displays which are described later in this section.

The aft center console is enlarged to two standard widths in both updates and lengthened to 24 inches in the moderate (Figure 11) and 27 inches in the major (Figure 16) update. The throttle quadrant (item 1 in both figures) is configured identically in both designs with the removal of the radar scope, a slightly forward positioning of the flap control (Figure 11, item 13; Figure 16, item 14), and the addition of a rudder power switch (item 2 in both figures), a gear horn switch (Figure 11, item 12; Figure 16, item 13), and an engine start panel (item 3 in both figures). In both designs, a radar control panel (Figure 11, item 9; Figure 16, item 6) is added, the rudder trim (item 7 in both figures) is offset to the left of center, and the aileron trim (item 8 in both figures) is moved aft.

This completes the list of changes to the KC-135 avionics suite that are identical in the moderate and major updates. In addition, a number of changes which are not common to both are made. These are discussed next.

Remaining Changes To The Moderate And Major Updates

The center instrument panel in the moderate design (Figure 9), in addition to the previously mentioned changes, has a consolidated caution and warning system annunciation panel (item 10) with dedicated lights which illuminate in conjunction with master caution lights (item 5) on the glare shield. The major design (Figure 14) broadens this concept with a consolidated caution and warning panel (item 11) displaying six lines of computer prioritized information. This system is integrated with an automatic display of emergency checklist procedures selectable by the pilot. In addition, in the major design, an attitude heading reference system (AHRS) control (item 12) is added to the center instrument panel.

The old fuel panel area (forward center console) in the moderate (Figure 9) and major (Figure 14) designs has several aforementioned changes from the current tanker configuration. In addition, the moderate design has lighted vertical scale fuel quantity

indicators (item 27). Also, an INS control panel (item 28) and a doppler control panel (item 26) are provided in this area. By contrast, the major update eliminates the vertical scale fuel quantity indicators with the addition of a multi-purpose CRT (item 26) which provides either weather radar or fuel quantity information depending upon which mode is selected. Additionally, a push-button fuel-switching matrix (item 27) is provided directly below the CRT.

The overhead panel of the moderate update (Figure 10) contains an AHRS control (item 8), an HF radio head (item 9), a VHF radio head (item 10), and a second TACAN (item 12). The rest of the changes to this panel are the same in both designs and have been discussed earlier. Similarly, the side panel configurations (both pilot and copilot) are identical in the moderate (Figure 12) and major (Figure 17) systems and the changes have been previously discussed.

As in the case of the side panels, no differences exist in the throttle quadrant of the moderate and major designs.

Although many changes from the current KC-135 control stand are identical in the aft center console of the moderate and major configurations, a number of dissimilarities also exist. In the moderate update aft center console (Figure 11), a fuel switching matrix (item 11) is added as are an IFF/SIF control panel (item 10) and the UHF No. 1 and 2 radio control heads (items 5 and 6). On the other hand, the major design (Figure 16) differs here in that an INS control panel (item 11) and a doppler control panel (item 9) are added while all communication, navigation, and IFF tuning functions are integrated into singular devices (item 5). Two of these devices are represented on the console. Finally, a multi-purpose CDU (CRT and keyboard) (item 10) is provided for tasks such as fuel management, CG computations, take-off and landing data (TOLD), and checklist presentation.

Design Capabilities. Although many of the hardware items in the three designs (especially in the moderate and major) are identical, very often the capabilities represented by each piece have been reduced or enhanced depending upon the particular update in question. This section will discuss, in a limited manner, those devices which are changed from the current KC-135 and how the capabilities of those devices have been altered in each update design.

Inertial Navigation System (INS)

Minimum Update (Figure 6, item 6 and one unit at old nav station, not pictured). Two independent Delco Carousel IV-E INSs are represented and navigation information to the HSI is provided selectively from either unit. Both units are aligned and flight planned simultaneously through the use of the "remote" key on the CDU, enabling the second unit to provide redundant information in

case of failure of the first unit. A maximum of nine waypoints plus present position can be loaded into the INS at any one time. Information readouts (determined by the position of the data selector switch) and capabilities include track angle/groundspeed, heading/drift angle, wind (direction/speed), crosstrack distance/track angle error, desired track angle/systems status display, distance/time to next waypoint, distance/time between any two waypoints, alert indication, flight planned changes, auto/manual flight plan update, flight plan changes between waypoints, and present position check/update.

<u>Moderate Update</u> (Figure 9). The INS once again consists of two Carousel IV-E black box units which are interfaced with the pilot through the nav management CDUs, item 25 (to be described later), thereby eliminating the need for a Carousel IV dedicated control head. (However, one of these heads is provided at the old nav station for redundancy). The INSs are aligned as in the minimum update, but all programming occurs through the nav management system.

<u>Major Update</u> (Figure 14, item 25). Identical to the moderate update.

Doppler

<u>Minimum Update</u> (Figure 5). A doppler (item 2) which is compatible with the INS for air-alignment provides groundspeed and drift angle information to the INS and continuously provides a digital display of those parameters.

<u>Moderate Update</u> (Figure 9). Identical to the minimum update except that groundspeed and drift information are displayed on the nav management CDUs (item 25) rather than on the dedicated doppler control head.

<u>Major Update</u> (Figure 14, doppler information displayed on item 25). Identical to the moderate update.

Radar

<u>Minimum Update</u> (Figure 6). The radar is displayed on the scope (item 8) located to the left of the copilot's knee. The unit is capable of depicting the following modes: ground mapping returns, weather returns, or aircraft beacon returns, one at a time. Besides mode selection, other adjustable parameters include range control, antenna tilt control, gain control, antenna stabilization, and radar system pressurization.

<u>Moderate Update</u> (Figure 9). The radar is displayed on the pilot's and copilot's CRT horizontal situation displays, item 20 (HSDs to be described later). The information displayed is selectable and depicts either ground mapping returns, weather returns, or aircraft beacon returns, one at a time. The range control is moved

to the HSDs to provide individual range control for each display. In addition to having the same other adjustable parameters as the radar in the minimum update, a radar cursor control (item 24) enables a cross hair to be moved about and positioned at any desired location on the display. When the cursor's position is subsequently inserted into the nav management system, the mission computer can calculate the relative location of the aircraft to the cursor, thus providing a radar update capability for navigation accuracy. Also, an automatic feature of this radar system displays a warning symbol on the HSD for nearby weather cells if the radar is on weather mode, but a radar overlay is not being displayed on the HSD at the time.

Major Update (Figure 14, radar information displayed on item 21). Identical to the moderate update.

Performance Scroll

Minimum Update. This scroll, located on the glare shield just above the engine fire switches, provides a quick readout of certain performance data which is usually obtained from the checklist binder or aircraft technical order. Such data includes approach, touchdown, and holding speeds for various gross weights, an altitude reminder, dry EPR values for take-off rated thrust (TRT), military rated thrust (MRT), and go-around (GA), EPR or touch and go landings, and military rated thrust for practice breakaway maneuvers between FL260 and FL350 (not depicted in figures).

Moderate and Major Updates. Not applicable. The information contained on the minimum update's performance scroll is computed and selectively displayed on the navigation management displays.

Attitude and Heading Reference System (AHRS)

Minimum Update. Not applicable.

Moderate Update (Figure 10). An AHRS (item 8) providing gyro-stabilized information for lateral, pitch, and roll axes of the aircraft is represented. Heading information is fed to all heading indicators in the cockpit with the exception of the standby magnetic compass while pitch and roll inputs are routed to the ADI/ flight director.

Major Update (Figure 14, item 12). Identical to the moderate update.

Fuel System

Mimimum Update (Figure 4, item 36). Unchanged from the current KC-135A.

Moderate Update (Figure 9). The fuel quantity indicating system (item 27) is made up of vertical scale, lighted segment indicators, one for each of the ten tanks plus a total fuel quantity indicator, a fuel transfer totalizer, and a transfer rate display. The fuel weight in each tank is sensed and displayed on the fuel quantity indicators and is automatically fed into the mission computer, so that the weight can be used in center of gravity and takeoff and landing data (TOLD) computations. The weight and balance/CG page on the nav management CDU is used to insert cargo and passenger weight and, when combined with the weight of the fuel in the tanks, can provide a display to the pilots of the present and optimum center of gravity range. All information is continually updated as fuel is used or transferred.

A fuel switching matrix (Figure 11, item 11) consisting of thirty alternate-action type switches controls fuel boost pumps, fuel system valves, air-refueling pumps and valves, and the fuel dump system. This matrix also controls the flow and routing of fuel for the whole aircraft system.

Major Update. The fuel system in this configuration is represented as an automatic system for the KC-135 and is programmable through an alphanumeric keyboard with a CRT display (Figure 16, item 10) which are located on the aft center console. Fuel quantities per tank are sensed and displayed. Desired center of gravity and offload fuel for refueling purposes are programmed on the keyboard and monitored through the display while the system operates automatically. Fuel quantity can also be monitored on a multipurpose display (Figure 14, item 26) located on the foward center console. The fuel management CDU is also used to program and calculate the center of gravity for the aircraft, take-off and landing data, and to display checklists. All updating of such information occurs automatically through the mission computer.

A backup fuel switching matrix (Figure 14, item 27) identical to the one represented in the moderate update is installed for redundancy and permits the crew to manually control the fuel boost pumps and fuel system valves, air refueling pumps and valves, and the fuel dump system thereby overriding the automatic system, if necessary.

In both the moderate and major update packages, the aft boom operator's station (Figures 13 and 18, respectively) is modified with two fuel quantity indicators which are repeaters off those located in the cockpit -- the total aircraft fuel quantity and the total aerial refueling transfer quantity/rate indicator. Additionally, the station is equipped with air refueling pump control switches for the forward and aft body tanks identical to those on the fuel switching matrix. This allows the boom operator to perform most refueling functions from his station thereby relieving the copilot of the task. However, complete monitoring and control can be performed from the cockpit.

Switching Panels
(Hydraulic, instrument power, and anti-icing controls)

Mimimum Update (Figure 7, item 4; Figure 4, item 27; Figure 8, item 1). Hardware design and equipment location are unaltered from the current KC-135.

Moderate Update (Figure 10). The hydraulic control panel (item 21) contains eight mini-toggle switches which group together most of the hydraulic switching controls previously scattered throughout the cockpit and consolidate them on a single panel located in the overhead switching panels (pump supply switches, system pressure switches, and auxillary pump switches). The capabilities represented are identical to the current KC-135.

The instrument power panel (item 20) is made up of three mini-toggle switches which consolidate electrical and instrument type switching functions from various places in the cockpit onto the overhead panel (battery switch, copilot's instrument power generator switch, and the IFF antenna selector). The capabilities represented are identical to the current KC-135.

The anti-icing panel (item 19) consists of six mini-toggle switches and consolidates anti-icing and similar controls from various places in the cockpit onto one switching panel. It is also located on the overhead panel (pitot heat, engine anti-ice, Q-inlet heat, window heat (2), and electronic cabinet cooling fan). The capabilities represented are identical to the current KC-135.

Major Update (Figure 15; items 7 and 8). Identical to the moderate update.

Caution/Warning Indicators

Mimimum Update. Unchanged from the current KC-135 configuration.

Moderate Update (Figure 9). A caution/warning annunciation system is provided to alert the pilots of any malfunction of aircraft systems or hardware. It consists of two master caution lights (item 5), one located in the glare shield in front of each pilot, and a central caution and warning light panel (item 10) consisting of 45 individual legend lights, located on the center instrument panel. Sensors or testing devices within the hardware automatically cause both master caution lights and the appropriate dedicated caution or warning light to illuminate when that equipment malfunctions. This alerts the pilot to take necessary corrective action.

Major Update (Figure 14). An electro-optical caution and warning annunciator display (item 11) is represented and consists of six lines of information to display cautions and warnings on a prioritized basis. When failures occur, they are displayed according

to their priority. The top five lines of the display continually readout the top five priority malfunctions, if in fact five have occurred. The bottom line of the display is used to show other failures on a rotating basis, each appearing for a period of two seconds prior to the next cycling into view (cycling can be put on hold if desired). Numbers appear on the right side of the display to indicate the number and priority of the failures. The number opposite the top line indicates the total number of failures that have occurred and the number following each successive line indicates the priority number for the specific failure. A switch adjacent to each display line, when pressed, arms the system so that the emergency procedure checklist for that failure can be automatically displayed on a CRT on the aft center console (Figure 16, item 10), if so desired by the pilot.

Communication, Navigation, and IFF Tuning

Mimimum Update. Unchanged from the current KC-135 except that a VHF communications radio (Figure 8, item 3) is added.

Moderate Update. Represented capabilities remain unchanged from the minimum update. Some equipment additions and location changes are made.

Major Update (Figure 16). An integrated communications, navigation, and IFF tuning system allows communications, short-range navigation, and IFF functions to be tuned and displayed on dual CDUs (item 5) which are installed in the aft center console. Eight frequencies or modes can be displayed on each CDU simultaneously with the frequencies for a given radio always being displayed in the same position opposite a specific line select key. During normal operation each radio is always tuned from one or the other designated CDU, however, radios can be tuned from the opposite CDU through a switching process.

The two top lines on each CDU provide an active and a standby frequency for any radio. Frequencies are set through toggle switches which are pressed up or down to incrementally change any digit in the frequency. A SELCAL (Selective Call) system enables the aircraft to be paged through the sounding of a tone and the illumination of a special SELCAL switch. This feature eliminates the need for constant monitoring of the HF radio. In addition, a "transfer" function enables the interchanging of control and display between the pilot's and copilot's CDUs.

Horizontal Situation Display (HSD)

Minimum Update. Not applicable.

Moderate Update (Figure 9). The HSDs (item 20) are located on the pilot's and copilot's instrument panels, immediately below the ADIs. The device replaces the standard HSI and presents plan-view

navigation information, radar information, or a mixture of both. The information on the display is controlled through a switching matrix located adjacent to the display. Because switching functions for the two displays are independent of each other, each pilot individually selects his display mode. The HSDs are used in conjunction with the flight director system, navigation computer, and the integrated navigation control-display units. Three groups of display functions are controllable through the switching matrix: navigation mode selection, HSD format selection, and radar and function selection.

Capabilities represented by nav mode selection include the availability of computer generated navigation information to the HSD for display through the HSD modes, TACAN course guidance information (in conjunction with a selected course) to be displayed on the HSD, and VOR or ILS course guidance information (in conjunction with a selected course) to be displayed on the HSD.

HSD format capabilities include the display of the HSI format with course and bearing information being relative to either a) the computer generated flight plan course, b) a selected TACAN station, or c) a selected VOR station, if a VOR frequency is tuned in the respective R/T unit, or localizer course deviation and glide slope deviation if an ILS frequency is tuned in the selected RT unit. In addition, a "map" format (which can also be modified to display plan-view navigation information to assist in the accomplishment of an ILS approach) is available as are holding pattern and rendezvous pattern formats (with parameters for these being defined through the navigation management CDUs).

Proper selection of the HSD radar and function switches enable either radar alone or radar overlayed on any HSD format (except HSI) to be displayed. Weather radar, ground mapping radar, and beacon radar are available. Through the use of a "range/scale" switch, the range of displayed information becomes either compatible with the format and/or is pilot selectable. A "north-up/track-up" switch allows reorientation of the displayed format to either a north-up or track-up presentation. A "clutter" switch either adds or deletes computer generated navigation information (nav aids, airfields, obstructions, etc.) from the "map", "hold/rz", or "ILS" display formats and a "course set" knob is provided which has the same function as that located on the HSI of the existing KC-135. Pictures of sample HSD formats are included in Appendix I.

Major Update (Figure 14, item 21). The only difference between the HSDs of the moderate and major updates is that the HSI format on the major update contains two (instead of one) bearing pointers thereby necessitating extra navigation mode selector switches and (depending upon the particular mode chosen) providing course deviation and bearing information relative to either identified waypoints or navigation aids.

Navigation Management System

Minimum Update. Not applicable.

Moderate Update (Figure 9). The pilot/aircraft interface device for the nav management system consists of two alphanumeric keyboard/CRT control/display units (item 25), one unit located on each side of the forward center console. A "control" switch allows either pilot to take control of the alphanumeric and symbolic key portion of the keyboard and enables him to insert "scratch pad" information into the system via the adjacent line keys. Although something typed on the scratch pad appears on both CRTs, the information can only be entered through the one with control.

Seven of ten special function page keys depicted (page A23), plus two that are not depicted, were evaluated during the mockup exercise. Those evaluated were: "direct to", "flight plan", "present position", "nav aids", "fuel status", "hold/rz", "flight plan freeze", "CG", and "TOLD". These special function pages operate independently of the control switch so that different ones can be displayed on each CDU simply by pressing the specific function key on the keyboard. A "waypoint data page" and "nav aids data page" can be displayed by first displaying "flight plan" or "nav aids" and then pressing the line key adjacent to the desired waypoint. The flight plan page can also be displayed by pressing the "direct to" key. The purpose of the pages is:

Flight Plan Page - displays the sequential list of 3-dimensional waypoints that define the aircraft route.

Waypoint Data Page - displays waypoint data relevant to the presently selected waypoint.

Present Position Page - displays current aircraft lateral performance data.

Navigation Aids Page - displays identifiers for all prestored navigation aids, airway intersections and airfields, arranged alphabetically.

Navigation Aids Data Page - displays all prestored information concerning selected navigation aids, intersections and airfields.

Fuel Status Page - displays fuel quantity per tank and total.

Holding/Rendezvous Page - displays information on a designated holding pattern or refueling track.

The Direct To special function displays the flight plan page with the added capability to navigate from the aircraft's present position directly to a newly defined waypoint or to any flight plan waypoint.

The Flight Plan Freeze function prevents automatic update of the flight plan at waypoint passage so that navigation outbound from a waypoint can be accomplished. This function can also put the present position latitude/longitude display in hold so that the information can easily be read and utilized by several aircraft in the same formation. This enables them to crosscheck their navigation systems for proper alignment with each other at any moment during flight without disturbing the automatic updating characteristics of the mission computer.

In the moderate update, the nav management system also is presented as having the capability to compute center of gravity and takeoff and landing data, although the mechanics for those operations had not been programmed into the system at that time.

CG Page - displays information necessary for computation of center of gravity of the aircraft, the actual center of gravity, and the center of gravity limits.

TOLD Page - displays information necessary for computation of takeoff and landing data and other TOLD data selected by the pilot.

Major Update (Figure 14). The nav management system (item 25) in the major update represented the identical capabilities as in the moderate design except that center of gravity and takeoff, landing data computations were performed through the fuel management CDU (Figure 16, item 10) rather than the nav management system.

General overall differences in equipment and related capabilities among the three update designs are presented in Tables 2 and 3.

Apparatus. The KC-135 mockup itself consisted of an actual size KC-135 cabin representation which contained a pilot's and copilot's station arranged in a side-by-side configuration, a "navigator's" station (used by the boom operator) located behind the copilot and facing inboard, and the inside experimenter's station.

When the mockup was configured with the minimum update design, all controls and displays were actual KC-135 hardware although few were operational. When configured to the moderate and major updates, magnetized, cardboard-backed photographs of hardware were used to facilitate location changes and equipment rearrangement. In all three configurations, the communications and interior lighting systems were operative. In the minimum update, the performance scroll was operative, while in the moderate and major systems one CDU of the navigation management system was programmable and operational.

EQUIPMENT CHANGES

Table 2

	MINIMUM UPDATE	MODERATE UPDATE	MAJOR UPDATE
Caution/Warning System	Current KC-135 caution/warning systems indicators	Single panel containing virtually all caution/warning indicators with a separate master caution indicator	A CRT capable of displaying a list of failures that have been prioritized for urgency by a mission computer. Adjacent keys interact with an additional MPD CRT which displays appropriate emergency checklists.
Navigation Management	Dual Carousel IV INS with dedicated control heads	Dual mass memory nav management systems each with a CRT display and keyboard control integrated with doppler and AHRS	Same as moderate
Comm/Nav Tuning	Conventional dedicated control heads	Conventional dedicated control heads	2 integrated comm/nav tuners each with a CRT control/display
Navigation Displays	2 conventional HSIs, 1 conventional radar CRT, 2 Carousel IV INS heads	2 HSDs (CRTs: also function as multipurpose radar overlay displays), 2 nav management system CRTs, 2 BDHIs	Same as moderate except that a center panel CRT is added for WX information and fuel management

EQUIPMENT CHANGES

Table 2 (cont'd)

	MINIMUM UPDATE	MODERATE UPDATE	MAJOR UPDATE
Aircraft Systems Monitors	Conventional round-dial instrumentation	Vertical scale instrumentation for RPMs, temperature, pressure, quantities, digital readouts of certain selectable parameters	Same as moderate
Fuel Management	Current KC-135 fuel control panel	Vertical scale fuel quantity gauges and a redesigned fuel switching matrix	1 CRT which displays either vertical scale fuel quantity gauges or WX radar, redesigned fuel switching matrix acts as a back-up to an automatic fuel transfer/pumping system
Checklists	Conventional checklist binder	Conventional checklist binder	Checklists are displayed on the center console CRT, emergency checklists are displayed in conjunction with annunciation panel
Aerial Refueling Control	Current KC-135 boom operator's panel -- fuel offload is controlled from current fuel panel on flight deck	Boom operator controls fuel offload from an updated boom operator's panel	Same as moderate

CAPABILITIES DIFFERENCES

Table 3

	MINIMUM UPDATE	MODERATE UPDATE	MAJOR UPDATE
Subsystems Controls	Current KC-135 decentralized systems controls for hydraulic, instrument, and anti-ice power	Centralized grouping of aforementioned systems according to function in a central (pilot accessible) location	Same as moderate
Center of Gravity	Conventional procedures	Automatic computation with the programming and displaying of pertinent parameters through the nav management CDUs	Automatic computation with fuel weight and distribution sensing; cargo, passengers, etc. programmed and displayed through a systems management CRT MPD
Energy Management	Conventional tech order procedures	EPR command	Same as moderate

CAPABILITIES DIFFERENCES

Table 3 (cont'd)

	MINIMUM UPDATE	MODERATE UPDATE	MAJOR UPDATE
"TOLD" Computation	Conventional tech order procedures	Automatic computations with the programming and displaying of pertinent parameters through the nav management CDUs	Automatic computations with fuel weight and distribution sensing, OAT sensing, PA sensing and other parameters programmed through a mission management CRT MPD
Fuel Control Panel	Current KC-135 configuration and capabilities	Manual fuel switching matrix	Automatic fuel transfer and pumping with a manual (back-up) fuel switching matrix
Checklists	Conventional tech orders	Same as minimum	Presented on a mission CRT; emergency checklists are displayed in conjunction with the caution/warning CRT

An outside experimenter's console provided a station for the two outside experimenters. It contained the following: two AIC-18s (interphone control units with multi-channel transmit and receive capability), communications monitoring lights which allowed the two outside experimenters to monitor the position of the pilot's and copilot's transmitter selector switches and additionally to identify which pilot was keying his microphone, a 24-hour hack clock with sweep second hand, lights and lighting controls, fasteners to hold maps and charts, a startable/stoppable elapsed time clock, a CRT repeater of the nav management CDU, a CRT to monitor cockpit activity, and a cassette voice recorder for recording all transmissions between the experimenters and the crew members.

On a table situated next to this experimenter's console were two cassette recorders to input voice and aircraft noise into the comm system and a video tape recorder capable of recording cockpit activity from the monitor.

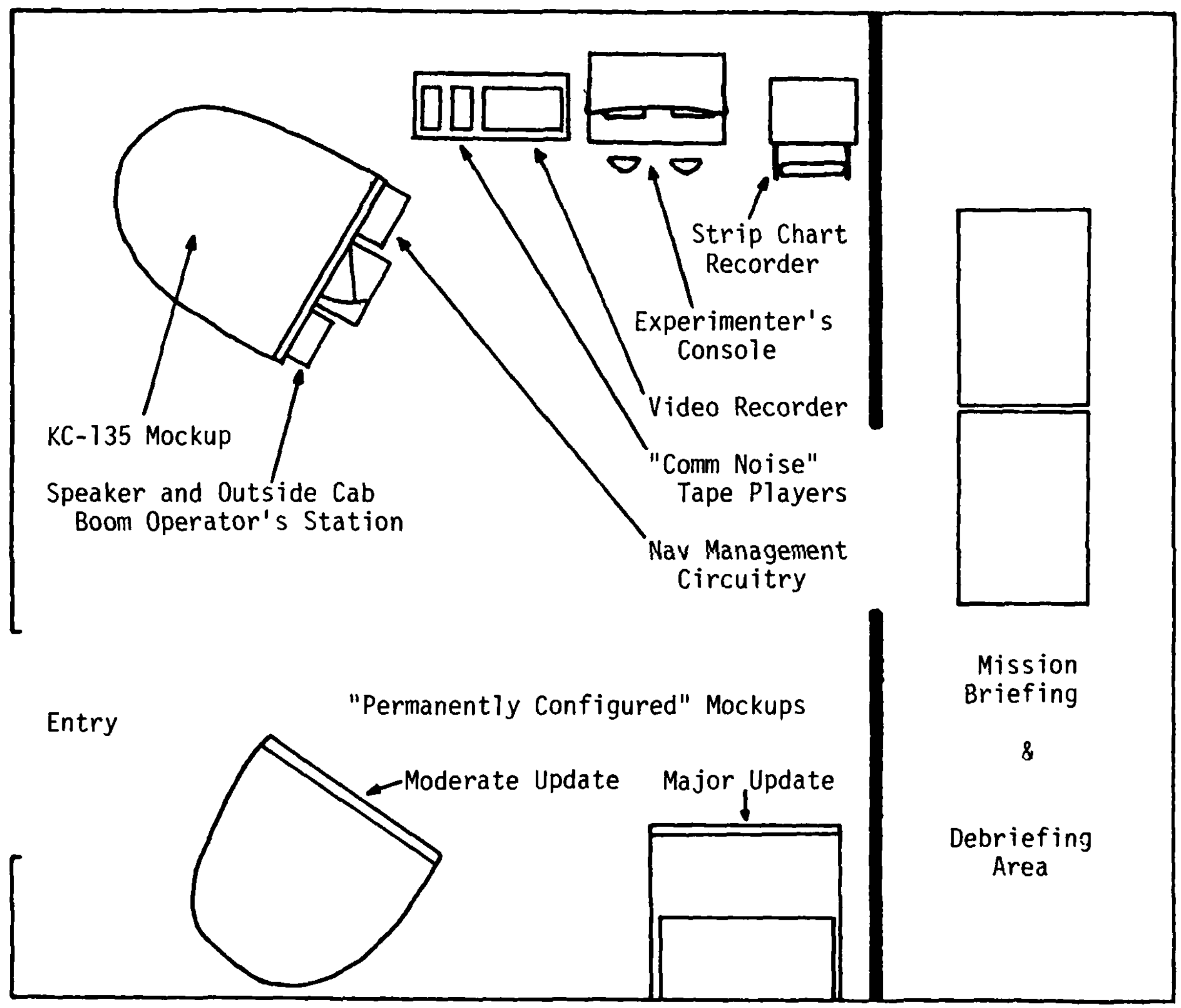
A table located just outside of the mockup's entry door contained an AIC-18, a speaker, and mockup representations of the standard and upgraded aft boom station. The boom operators would sit at this table during the refueling portions of their missions.

Two other mockups provided additional representations of the moderate and major updates. These were used for crew familiarization with the two designs and also provided facilities for checklist procedures to be run while the "experimental" mockup was in use.

The inside experimenter's console included an AIC-18, a reading lamp, a worktable, and the mockup air-conditioning controls. All experimental apparatus is depicted in Figures 19 and 20.

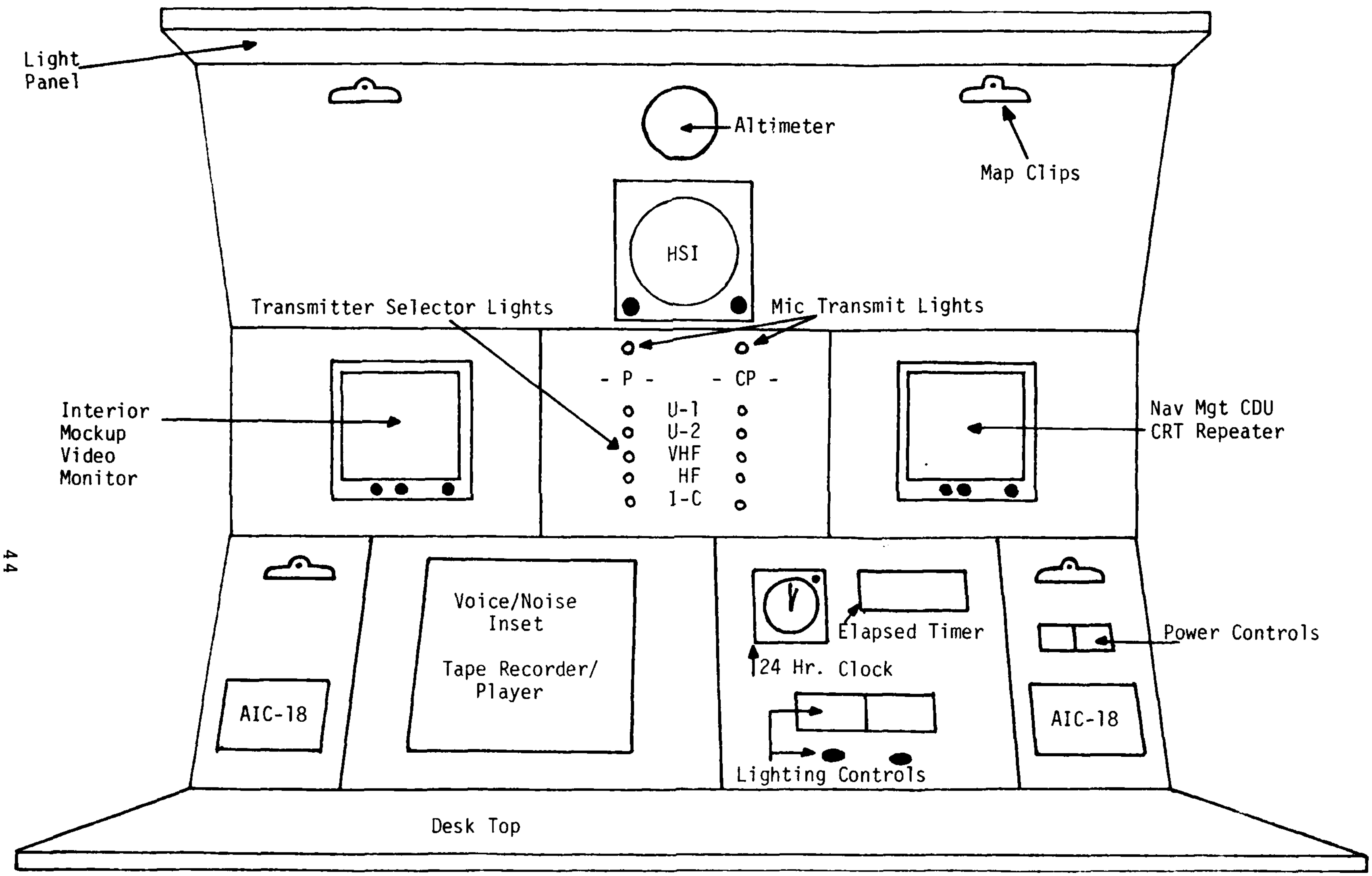
Procedures. Three crews (a pilot, copilot, and boom operator per each crew) participated in the mockup evaluation during each of the three weeks of data collection. The same schedule was followed each week and involved briefing/training sessions on Monday, design configuration evaluations in the mockup on Tuesday, Wednesday, and Thursday, and a debriefing/crew comment session on Friday.

The briefing and training sessions on Monday included all three crews which were to participate for that week and consisted of a program overview and briefing, a review of the week's schedule, and short explanations concerning the questionnaires to be used in the study. The remainder of that day was dedicated to describing the design philosophy for the three cockpit configurations to be evaluated and to presenting detailed systems briefings. In addition,



Mockup Area Configuration

Figure 19



TAACE Experimenter's Station

Figure 20

the crews were given short instructions on the types of missions involved in the scenario and suggestions on ways to make the mockup exercise as productive as possible.

On Tuesday, Wednesday, and Thursday, data collection ensued with each crew being briefed in great detail on the specific aircraft systems to be flown that day and "flying" one mission leg and one cockpit configuration that day. As Table 4 shows, each mission leg and cockpit design were paired together only once each week, so although each crew did not evaluate all possible treatment combinations, all combinations were evaluated once by the end of each week. This matrix was followed for all three weeks of data collection thereby yielding a total of three replications for each mission leg/design combination.

On Friday, all crews for that week participated in an open debriefing session in which their final comments and criticisms regarding the update designs, mission scenario, program objectives and approach, or any other pertinent issues were solicited and recorded.

Prior to stepping into the mockup, each crew was briefed (much in the same manner as in SAC Operations at their home bases) about its mission, call signs, receivers, and formation size. Information regarding communications, taxi, take-off, climb, level off, join-up, rendezvous, refueling, and recovery was briefed as well as weather on track and emergency procedures. If applicable, "intelligence" briefings outlined pertinent political instability. In addition, mission kits which contained completed copies of all necessary preflight and inflight forms, were distributed, time hacks were obtained, and the crew completed nav planning and predeparture tasks.

Once inside the mockup, each crew was reminded that the only way it could reasonably evaluate each design would be for each member to project himself totally into the mission. For the crew members, this entailed making believe that they were on an actual mission: they should respond to and make any necessary communications, twist knobs, flip switches, monitor instruments and gauges, maneuver the yoke and other controls when necessary, and in general act and conduct themselves as if they were actually flying a tanker. They were to follow these procedures even though they were receiving no feedback because the instrumentation was mostly photographic representations of displays and controls without dynamics.

One area of this evaluation where the mockup exercise did not resemble the real-world workload situation involved the decoding of secret messages. This decoding process was mimicked through the use of phonetically transmitted messages, but was always kept at a simple and unclassified level to avoid the compromise of any sensitive materials or processes.

Table 4. Experimental Schedule

CREW NUMBER	MONDAY	TUESDAY			WEDNESDAY			THURSDAY			FRIDAY
		RUN POSITION	MISSION LEG	DESIGN UPDATE	RUN POSITION	MISSION LEG	DESIGN UPDATE	RUN POSITION	MISSION LEG	DESIGN UPDATE	
1	BRIEFING AND TRAINING SESSIONS	1	1	MINIMUM	3	3	MAJOR	2	2	MODERATE	DEBRIEFING SESSION
2		2	3	MODERATE	1	2	MINIMUM	3	1	MAJOR	
3		3	2	MAJOR	2	1	MODERATE	1	3	MINIMUM	
4		1	1	MINIMUM	3	3	MAJOR	2	2	MODERATE	
5		2	3	MODERATE	1	2	MINIMUM	3	1	MAJOR	
6		3	2	MAJOR	2	1	MODERATE	1	3	MINIMUM	
7		1	1	MINIMUM	3	3	MAJOR	2	2	MODERATE	
8		2	3	MODERATE	1	2	MINIMUM	3	1	MAJOR	
9		3	2	MAJOR	2	1	MODERATE	1	3	MINIMUM	

Along with the crew, each session involved a minimum of four AFFDL experimenters. Two experimenters were on the interphone system stationed outside the mockup and maintained crew communication by interfacing with the crew as other aircraft in the formation, ground control agencies, and airborne agencies. A third experimenter, who was also on interphone, was located inside the mockup and observed the crew in action.* The fourth experimenter also was on interphone and was located inside the mockup and acted as an instructor to the crew. Because of the unfamiliarity and relative sophistication of most of the equipment that the crews were being asked to evaluate, it was the fourth experimenter's job to answer questions on how any device operated and what capabilities were being represented.

Following each "flight", a questionnaire addressing projected hardware capabilities and information quality, workload levels, system requirements, and many other related issues that pertained to that particular design update was administered to the crew members. Pilots and copilots received identical questionnaires in all instances -- therefore responding to the same issues -- while boom operators completed questionnaires which addressed slightly different aspects of the design. Crews were instructed not to discuss their evaluations and opinions with other crews until the Friday debriefing session because those other crews might not have been exposed to that configuration in the mockup setting and biased data might have resulted. The members of a crew were permitted to discuss a configuration among themselves. In addition, on Monday pre-mockup questionnaires were administered which chiefly established the crew experience levels and obtained basic opinions regarding the adequacy of the current KC-135; and, after the third "flight", post-mockup questionnaires were administered which addressed "overlooked" issues. These questionnaires also obtained further comments relating to crew/system requirements to accomplish the refueling mission and allowed the crews to evaluate and criticize the mockup exercise and the experimental procedures in general.

In addition to the three design updates, the subject crews evaluated the concepts of designating the boom operator as a positive control crew member and having the copilot primarily responsible for assuming the navigation tasks. In addition to positive control crew member duties, the boom operator would assume greater responsibility for a) copying and decoding messages and keeping the secrets books, b) reading checklists, c) monitoring the comm radios as directed (normally HF) and communicating as required, d) recording inflight data such as fuel management, mission progress on JN charts, 781 write-ups, inflight engine data, and comm logs, e) monitoring engine instruments and aircraft subsystem indications,

* This experimenter also administered a secondary task to the pilots and copilots as a workload measure. The results of this "mini-experiment" are presented in a separate document.

f) computing center of gravity, takeoff and landing data, and programming the automatic fuel system through the keyboard/CRT control/display unit on the appropriate crew station configurations, and g) operating the air refueling pumps from the aft boom station on the appropriate configurations. At the same time, he would be relieved of the "cargo/passenger" duties that he now performs, and these would be handled by the ground crew and a designated "troop commander". The copilot would perform most of the communication and navigation functions in addition to his present duties. He would be responsible for: a) operating the IFF and code 4 box, b) programming and operating the inertial navigation system (or nav management system) and the doppler, c) operating the radar including weather, ground-mapping, and beacon, and d) performing the rendezvous. The pilot would also assume increased tasking such as additional comm (primarily VHF), monitoring weather radar, IFF, and the nav management system. These measures would help to alleviate the increased workload falling upon all the crew members as a result of eliminating the navigator position. Table 5 gives a general description of the tasks that each crew member would be responsible for handling.

Table 5. Crew Position Task Allocations

	Predominantly Pilot	Predominantly Copilot	Predominantly Boom Op	Both Pilots Equal	All 3 Equal
Reading checklists		*	*		
Launch message			X		
Flight planning				X	
Inputting flight plan into nav management system				X	
Monitoring PPSN and progress		X			
Departure briefings	X				
Approach briefings	X				
A/R fuel control		X			
Tuning comm radios				X	
Tuning nav radios				X	
Comm with ATC		X			
Comm with cell formation	X				
Comm with command post	*		*		

* Task was shared equally between these two individuals

Table 5 (cont'd). Crew Position Task Allocations

	Predominantly Pilot	Predominantly Copilot	Predominantly Boom Op	Both Pilots Equal	All 3 Equal
Rendezvous comm	X				
Copy coded messages			X		
Aircraft systems operations				X	
Rendezvous navigation				X	
Weather radar				X	
Ground mapping radar				X	
Rendezvous radar				X	
Monitoring engine instruments and C/W indicators				X	
Fuel management					X
Monitoring flight instruments				X	
Outside watch				X	
Airborne radar approach (fly)	X				
Airborne radar approach (direct)		X			

Table 5 (cont'd). Crew Position Task Allocations

	Predominantly Pilot	Copilot	Boom Op	Both Pilots Equal	All 3 Equal
Map position monitor		X			
AFTO Form 781			X		
Weight and balance			X		
Flight log			X		
T/O, landing data		X			
Determining enroute power settings				X	
Aircraft control: Takeoff	X				
Enroute	X				
Approach	X				
Landing	X				
Crew coordination and command	X				

SECTION III

RESULTS

The data to be evaluated and discussed in this report will be that data resulting from the crew responses to the questionnaires and their subsequent debriefing comments. As previously mentioned, the objective workload measurement data which resulted from a pilot/copilot secondary task concurrent with the mockup exercise, will be presented in a separate report.

Three rating scales were used for the questionnaires. These scales are contained in Appendix II. Scale I was used to rate the quality of information on various displays (i.e. for readability, content, etc.) and also to rate the placement in the cockpit of certain controls and displays. Scale II was used in projecting workload levels, and Scale III enabled crew members to rate the capabilities represented by certain pieces of hardware and related these to the "degree of requirement" for that hardware. Although these subjective ratings do not define the same parameter across the scales, a 0 to 10 rating system was maintained for all three with 10 representing the "best" or "most" and 0 designating the "worst" or "least" on any continuum that might exist. All data ratings are averages based on the number of responding crew members (in all but a few instances that number was nine). Data resulting from questions that did not require a rating are simply frequency counts of the number of crew members who fell into or responded to that category.

First, the pilot, copilot, and boom operator data resulting from the cockpit design evaluations will be presented. This data will then be followed with crew position comparisons of the post-mockup questionnaire responses.

Pilot Design Evaluation Data

In reviewing the pilot data, the pilots responded that when compared to the workload level as it stands in the tanker today, the minimum update represented a moderate increase in workload while the moderate and major updates represented either no change or a very slight decrease in projected workload level. In evaluating the capabilities provided by each design, the trend was continued. The pilots felt the increased navigation capabilities offered by the moderate ($\overline{x}$=9.13, SD=.99)* and major ($\overline{x}$=8.22, SD=1.55) configurations' nav management system over the minimum's ($\overline{x}$=7.89, SD=1.58) dual INS was a virtual requirement and their comments demonstrated that they preferred (and classified as a requirement) the advantages represented by a horizontal situation display (the multipurpose CRT

* $\overline{x}$=average, SD=standard deviation

display device) as compared to the conventional horizontal situation indicator (the dedicated electromechanical instrument). The pilots also rated highly the aircraft engine and subsystem instrumentation in the moderate ($\bar{x}$=8.63, SD=1.51) and major ($\bar{x}$=7.22, SD=2.22) configurations (vertical scale instruments with digital readout capability) as compared to the conventional "round-dial" electromechanical instruments of the minimum configuration ($\bar{x}$=6.78, SD=2.67). In addition, they more highly rated the consolidated caution/warning panel of the moderate design as compared to the scattered-around-the-cockpit annunciation lights in the minimum and the prioritized alphanumeric listing panel in the major design.

Investigation of the feasibility of mission accomplishment with and without an upgraded boom operator revealed that the issue was really not as important as the upgraded avionics issue. In fact, the only time when the pilots felt that a boom operator's assistance would be genuinely helpful would be during an autopilot failure or in the case of one pilot incapacitation. Other than that, pilots rated mission accomplishment no more likely with an upgraded boom operator. However, increased navigation cababilityties (nav management system vs. dual INS) noticeably enhanced the probability of mission accomplishment--<u>especially</u> if an autopilot failure should occur, thus requiring one pilot to be hands-on-yoke at all times. The importance of the integrated comm/nav frequency tuners (major update), the control/display unit for fuel management and automated emergency procedures checklists (major update), and the upgraded aft boom station was judged to be very minimal by the pilots for mission accomplishment.

Generally, the pilots rated the information presented on the special function pages of the nav management system as being both sufficient in amount and good (7.33) to very good (8.89) in quality. The capabilities provided by those pages were rated from partial (7.21 for takeoff and landing data page) to absolute (9.09 for present position page) requirements. The most necessary requirements were flight plan, waypoint data, present position, direct to, and hold/rendezvous information. One interesting observation relating to the ratings of the capabilities of the nav management special function pages is that the major update was consistently rated lower ($\bar{x}$=7.79, SD=.80) than the moderate update ($\bar{x}$=8.54, SD=.69) special function pages even though those capabilities were almost identical (CG and TOLD pages were on the fuel management CDU in the major update). Furthermore, when asked to rate the overall capabilities presented in the three configurations for their usefulness and necessity in helping a 3-man crew accomplish the A/R mission, the pilots rated the moderate update the highest ($\bar{x}$=9.0, SD=1.07), the minimum second ($\bar{x}$= 8.11, SD=1.41), and the major lowest ($\bar{x}$=7.89, SD=1.31). Possible reasons for this finding will be discussed at some length later.

Not unexpectedly, pilots rated the workload level for the copilot to relay fuel flow information to the boom operator during refueling to be quite low ($\bar{x}$=4.56, SD=2.46). Monitoring fuel flow

on the other hand was judged to be highest for the minimum update ($\overline{x}$=6.11, SD=1.90) and lowest for the major ($\overline{x}$=5.0, SD=1.20). They also indicated that a minimally experienced crew would have difficulty accomplishing a mission with the minimum configuration but would not have difficulty if flying the moderate or major updates.

Except in the case of navigation tasks, pilots projected the percentages of total workload from navigation, communication, piloting, aerial refueling, paperwork and other tasks to be nearly identical in the three different configurations (see Table 6). When required to rate the workload level itself for those various tasks (see Table 7), once again all three configurations received nearly identical ratings (including those for navigation tasks). Pilot workload ratings for the mission segments (see Table 8) were also nearly identical for the three configurations and followed the same pattern in each configuration. Departure, aerial refueling, descent, approach and landing were the areas of greatest workload while climb and cruise segments were much less so.

In the minimum configuration, (but not in the moderate or major update) pilots appeared to be very unhappy with the radar which was the same as is currently installed in the KC-135. Fuel management caused a bit of concern in the moderate design while "see and avoid" and checklist procedures generated concern in all three configurations. The workload ratings and these areas of concern will be discussed at some length later.

Finally, the pilots appeared to be most satisfied with equipment locations in the moderate ($\overline{x}$=8.0, SD=.61) and major ($\overline{x}$=8.11, SD=.35) updates (locations were almost identical for the two designs) and only marginally satisfied with equipment locations in the minimal update ($\overline{x}$=6.77, SD=.51). They also said by a 2-to-1 margin that aft boom station fuel flow totalizers, pump switches, and transfer rate gauges did not significantly reduce their refueling workload and rated the requirements for such devices to be nice, but not necessary ($\overline{x}$=4.83, SD=2.06).

Copilot Design Evaluation Data

As one would probably expect, the data provided by the copilots strongly mirrored and in most cases underscored the pilots' data. The copilots felt that the minimum update represented a significant increase in workload while the moderate and major updates represented only a very slight increase in projected workload level. As did the pilots, the copilots agreed that the increased navigation capabilities offered by the moderate ($\overline{x}$=9.0, SD=.50) and major ($\overline{x}$=8.22, SD=1.56) configurations' nav management system over the minimum's dual INS ($\overline{x}$=6.56, SD=2.79) was a requirement. In addition, their ratings demonstrated that they thought the advantages represented by the horizontal situation display were requirements as compared to the conventional horizontal situation indicator.

Table. 6 Pilot Projected Percentage Workload as a Function of Task and Design Update

	MINIMUM	MODERATE	MAJOR
Navigation tasks	26.11%	22.22%	31.67%
Communication tasks	20.0 %	21.11%	18.33%
Piloting tasks	30.0 %	33.89%	31.67%
Aerial refueling tasks	12.22%	14.44%	9.22%
Paperwork tasks	5.0 %	3.56%	4.44%
Other tasks	5.71%	4.78%	6.0 %

Table 7. Pilot Projected Workload Level as a Function of Task and Design Update

	MINIMUM	MODERATE	MAJOR
Navigation tasks	6.83	6.0	6.11
Communication tasks	5.94	5.33	5.0
Piloting tasks	5.67	5.44	5.33
Aerial refueling tasks	5.33	4.89	4.67
Paperwork tasks	3.0	2.33	2.33
Other tasks	1.0	3.0	2.5

Table 8. Pilot Projected Workload Level as a Function of Mission Segment and Design Update

	MINIMUM	MODERATE	MAJOR
Departure	6.33	6.0	6.11
Climb	5.44	4.78	5.0
Cruise	5.11	4.33	5.11
Aerial Refueling	6.56	6.0	5.78
Descent	6.63	6.0	5.0
Approach and Landing	7.0	6.38	6.22

Also like the pilots, the copilots preferred the moderate ($\bar{x}$=7.33, SD=1.13) and major ($\bar{x}$=7.78, SD=1.56) systems' vertical scale engine and system instrumentation with digital readouts when compared to the minimum's ($\bar{x}$=6.44, SD=2.40) round-dial instruments, and most highly rated the concept of placing all caution/warning indicators on one centralized panel as in the moderate design ($\bar{x}$=8.33, SD=1.0). However, the copilots gave higher ratings to the prioritized alpha-numeric caution/warning panel in the major design ($\bar{x}$=7.56, SD=1.74) than did the pilots ($\bar{x}$=6.44, SD=1.36).

As did the pilots', the copilots' ratings suggested that the issue of upgrading the boom operator was not as critical as that of upgrading avionics, although the concept of making the boom operator a positive control crew member was highly regarded. The copilots felt that an autopilot failure and, to a lesser degree the incapacitation of one pilot, might be the only instances when an upgraded boom operator would enhance the prospects of mission accomplishment. However, the copilots were not as emphatic as the pilots in saying that the increased capabilities represented by the nav management system greatly increased the probability of mission accomplishment as compared to a dual INS, but once again they agreed that a system which included an integrated comm/nav frequency tuner, a control/display unit for fuel management and automatic emergency checklist display (major update), and/or an upgraded aft boom station was unnecessary to get the job done.

Almost without exception, the copilots rated the information presented on the special function pages of the nav management system as being both sufficient in amount and good (7.89) to very good (9.0) in quality. In most cases, the capabilities provided by those pages were rated as nearly absolute requirements (7.0 for center of gravity data page to 9.11 for flight plan page) with flight plan, waypoint data, present position, direct to, and hold/rendezvous information being regarded as the most important. Unlike the pilots, however, the copilots did not rate the major system as less desirable than the moderate and in fact, when they rated the overall capabilities of each configuration in helping to accomplish the A/R mission, the trend was in favor of increasing [illegible]ication with the minimum update being given the lowest rating ($\bar{x}$=[illegible]25, SD=1.86) and the moderate and major being rated much higher (moderate: $\bar{x}$=8.89, SD=.60; major: $\bar{x}$=9.11, SD=.60). [illegible], the pilots had rated the major slightly below the moderate design in effectiveness for accomplishing the A/R mission.

The copilots yielded almost identical responses as the pilots when rating their workload level to relay fuel flow information to the boom operator during refueling (copilots' rating: $\bar{x}$=4.67, SD=2.18; pilots' rating: $\bar{x}$=4.56, SD=2.46). The copilots also judged the monitoring of fuel flow to be highest for the minimum update ($\bar{x}$=6.11, SD=1.83) and lowest for the major ($\bar{x}$=[illegible].[illegible]8, SD=[illegible].19). Unlike the pilots, they thought that a minimally experienced crew would have no substantial difficulty flying any of the three design configurations.

The copilots r... the percentages of total workload coming from navigation, communication, piloting, aerial refueling, paperwork and other ... to be very close in all three configurations (see Table 9). When rating the workload level itself for those tasks, the rat... were even closer in the three configurations (see Table 10 ... though the copilots gave slightly higher workload ratings fo... minimum configuration than for the moderate and major during ... on segments (aerial refueling, descent, approach/landing), ... ern similar to that demonstrated by the pilots resulted: ... s, departure, descent, approach and landing were judged to be the areas of highest workload (see Table 11). Aerial refueling was given a higher workload rating in the minimum configuration ($\overline{X}$=6.. SD=1.72) than in either the moderate ($\overline{X}$=4.89, SD=2.26) or major ($\overline{X}$=5.2., SD=1.86) system which were also very close to the ratings for the climb segment.

The copilots' data suggested a slight concern about the radar in the minimum configuration and also a slight concern about accomplishing checklists in all three configurations. "See and avoid" was judged by half the copilots in all three designs to be so difficult to accomplish that it might pose a problem. As mentioned before, the see and avoid issue will be discussed at some length later.

The copilots were slightly more satisfied with the equipment locations in the moderate ($\overline{X}$=7.25, SD=.71) and major ($\overline{X}$=7.49, SD=.55) updates than in the miminum ($\overline{X}$=6.77, SD=.67) and they indicated by a 2-to-1 margin that aft boom station fuel flow totalizers, pump switches, and transfer rate gauges significantly reduced their workload during refueling but that requirements for such equipment were marginal ($\overline{X}$=6.37, SD=1.69).

Boom Operator Design Evaluation Data

The boom operators were slightly less satisfied with equipment locations in all three configurations (minimum: $\overline{X}$=7.34, SD=.47; moderate: $\overline{X}$=7.06, SD=.78; major: $\overline{X}$=7.5, SD=.47) than either the pilots or copilots ... their data did not differ noticeably among the three configurations. By a sizeable majority (a 3-to-1 margin), the boom operators felt it was necessary in all three configurations to have both the center console area and the old nav station accessible to them; in addition, by an 8-to-1 margin, they liked the way a proposed crew seat on an "L" shaped track maneuvered between the two crew stations.

Unlike the pilots and copilots, the boom operators indicated that, even in the minimum configuration, there was sufficient time to perform "see and avoid" duties (minimum: 2-to-1 margin; moderate and major: 7-to-2 margins). However, when asked to rate the overall capabilities presented in the three configurations to accomplish the A/R mission with a 3-man crew, a trend similar to that yielded

Table 9. Copilot Projected Percentage Workload as a Function of Task and Design Update

	MINIMUM	MODERATE	MAJOR
Navigation tasks	40.0 %	35.0 %	35.0 %
Communication tasks	22.78%	29.0 %	26.11%
Piloting tasks	9.06%	13.89%	12.89%
Aerial refueling tasks	14.11%	11.0 %	11.89%
Paperwork tasks	9.0 %	6.56%	9.0 %
Other tasks	6.78%	5.67%	4.56%

Table 10. Copilot Projected Workload Level as a Function of Task and Design Update

	MINIMUM	MODERATE	MAJOR
Navigation tasks	7.22	6.44	6.28
Communication tasks	5.44	5.56	5.67
Piloting tasks	3.78	3.33	3.89
Aerial refueling tasks	4.67	4.44	4.0
Paperwork tasks	3.88	3.78	3.56
Other tasks	-	3.88	3.38

Table 11. Copilot Projected Workload Level as a Function of Mission Segment and Design Update

	MINIMUM	MODERATE	MAJOR
Departure	5.89	5.78	5.56
Climb	5.11	5.0	5.44
Cruise	4.0	3.44	4.44
Aerial Refueling	6.22	4.89	5.22
Descent	6.78	5.88	5.78
Approach and Landing	7.44	6.5	6.67

by the pilots emerged -- that is, the boom operators rated the minimum update as the lowest ($\bar{x}$=6.5, SD=1.87), the moderate as the highest ($\bar{x}$=7.88, SD=1.13), and the major about midway between the two ($\bar{x}$=7.17, SD=1.33).

When boom operators assessed their projected percentage of total workload coming from navigation, communication, aerial refueling, paperwork, fuel management tasks, weight and balance calculations, see and avoid, and general free time, only navigation tasks and paperwork tasks demonstrated changes of more than 5% for the three configurations (see Table 12). Apparently, increased avionics sophistication convinced the boom operators that their paperwork would decrease (min: 16.1%, mod: 12.1%, maj: 9.5%) but not their navigation tasks (min: 10.8%, mod: 6.7%, maj: 15%).

Except for navigation tasks, there were no sizeable changes across the three configurations when the boom operators rated the workload level itself for the aforementioned tasks (see Table 13). In addition, the boom operators felt that a 2 pilot/1 boom operator crew could safely and adequately perform a mission with the minimum configuration (by a 5-to-3 margin) and, even more so, with the moderate or major design (by 8-to-1 and 9-to-0 margins, respectively), provided that SAC designated the boom operators as positive control crew members.

They did feel that transfer fuel flow rate and totalizer, aerial refueling pumps switches, and aircraft fuel totalizer increased their workload during refueling (7-to-2), somewhat jeopardized safety (5-to-4), and made aerial refueling procedures more complicated (2-to-1). They did not feel there was much of a requirement for these controls in either the moderate ($\bar{x}$=5.0, SD=3.66) or major ($\bar{x}$=5.64, SD=4.07) update and although the aft boom station was identical in both designs, the boom operators rated its quality higher in the moderate than in the major (moderate: $\bar{x}$=6.71, SD=1.98; major: $\bar{x}$=5.63, SD=1.67). It should be pointed out that the "requirements" ratings were extremely varied (ranging from 0 to 10 in both the moderate and major updates) as is shown by the large standard deviations in relation to the averages. The capabilities represented by having the same computerized weight and balance calculations and takeoff/landing data calculations located in a more available position to the boom operators in the major design probably caused them to rate those cababilities higher in the major ($\bar{x}$=8.5, SD=1.07) than in the moderate update ($\bar{x}$=7.56, SD=.53). In addition, the boom operators thought that automatic/programmable fuel management and emergency checklist displayed on a CRT were at least partial requirements (7.63 and 7.0, respectively).

Pilot And Copilot Post-Mockup Data

In reviewing the pilots' post-mockup questionnaire data, it became apparent that there was a wide variance of opinion as to how effectively the boom operator could be utilized for certain tasks.

Table 12. Boom Operator Projected Percentage Workload as a Function of Task and Design Update

	MINIMUM	MODERATE	MAJOR
Navigation tasks	10.78%	6.67%	15.0 %
Communication tasks	16.44%	15.44%	17.22%
Aerial refueling tasks	37.78%	40.56%	37.78%
Paperwork tasks	16.11%	12.1[illegible] %	9.56%
Fuel management	3.33%	4.0 %	3.89%
Weight and balance	4.78%	3.44%	4.11%
See and avoid	6.56%	6.33%	4.0 %
Free time	3.56%	3.33%	1.56%
Other (not listed above)	1.0 %	6.78%	5.78%

Table 13. Boom Operator Projected Workload Level as a Function of Task and Design Update

	MINIMUM	MODERATE	MAJOR
Navigation tasks	5.5	3.89	4.67
Communication tasks	5.44	5.56	5.67
Aerial refueling tasks	6.94	7.22	6.22
Paperwork tasks	5.56	4.56	4.89
Fuel management	2.88	3.11	3.56
Weight and balance	2.89	3.33	3.11
See and avoid	3.63	3.56	2.89
Free time	2.38	2.13	2.13

This fact may be partially due to reluctance on the part of the pilots to utilize a non-rated crew member to perform tasks previously accomplished by a rated one. It probably also explains why the areas of highest agreement were ones in which the boom operator may have had prior experience or where the task might be very easy to accomplish. Examples of such tasks were see and avoid, fuel monitor, weight and balance computations, emergency backup, copy/decode messages, and position recording. In general, this also held true for the copilots' data.

Both pilots and copilots saw very little need for a "boom engaged" light on the copilot's side in addition to the one on the pilot's side (as long as the pilot's was clearly visible to the copilot). In addition, pilots and copilots strongly agreed on the types of communication and navigation equipment necessary for a three-man crew. For example, two UHF, one VHF, and one HF radio is the minimum necessary comm equipment, with the copilots also wanting at least one FM, and both pilots and copilots indicating that SELCAL would not be required, but is desired. Requirements for the navigation equipment include a nav management system, a doppler, VOR/ILS, a TACAN, ADF, ground mapping radar, and dual INSs. No requirement exists for an accelerometer in the opinion of both the pilots and copilots.

When vertical scale instruments were used, both groups identified a requirement for selectable digital readout capability. They also recommended "all navigation functions integrated into one control/display" as being the minimum avionics update level for a three-man flight deck crew. For a two-man flight deck crew, the groups split about evenly between incorporating all navigation functions into one control/display, and incorporating all communication <u>and</u> navigation functions into a singular control/display as a minimum avionics update level. The copilots indicated a greater requirement for all annunciations to be on a CRT with a computerized priority listing than did the pilots (copilots: $\bar{X}$=6.56, SD=1.88; pilots: $\bar{X}$=4.44, SD=1.60), but both groups indicated about the same requirement for having emergency checklists integrated with the annunciator panel and automatically displayed on a CRT (copilots: $\bar{X}$=5.33, SD=2.40; pilots: $\bar{X}$=4.89, SD=2.07).

Both groups ranked the fully centralized annunciator panel as their first choice for a KC-135 caution/warning system (pilots by a 2-to-1 margin and copilots by 5-to-4), but a close second was the digital alphanumeric readout with a prioritized listing. Neither group really cared to keep the present scattered-around-the-cockpit caution/warning indicators as a viable alternative.

The pilots regarded an HSD as more of a requirement ($\bar{X}$=9.56, SD=.73) than did the copilots ($\bar{X}$=8.22, SD=1.92), and both groups rated the five HSD information categories -- symbol generated map, weather radar, HSI, ground mapping radar, and beacon -- as being required formats on the display (ratings ranged from a pilot/

copilot average of 8.61 for the symbol generated map to 9.34 for radar beacon). HSD information overlays which were highly rated as requirements by pilots and copilots were map with weather ($\bar{x}$=9.22, SD=.71) and map with beacon ($\bar{x}$=8.39, SD=.90), but the pilots rated the requirement for map with ground map noticeably higher than the copilots (pilots: $\bar{x}$=9.0, SD=1.12; copilots: $\bar{x}$=7.67, SD=1.80). Neither group rated the requirement for a color HSD as opposed to a black and white HSD very highly (pilots: $\bar{x}$=6.11, SD=2.23; copilots: $\bar{x}$=6.67, SD=1.67).

The mockup process/evaluation received generally favorable marks from pilots and copilots alike, with both groups leaning toward the belief that the unrealistic aspects of the mockup may have caused them to underestimate the difficulty of tasks involving navigation, piloting, and rendezvous procedures.

Boom Operator Pre And Post-Mockup Data

In both the pre and post-mockup questionnaries, the boom operators indicated that they would be very eager to perform in-flight duties that they do not now perform (assuming an increase in rating and pay). When given a list of various tasks connected with the tanker mission and asked which required no training and which required some training, the boom operators demonstrated a noticeable shift of opinion for only a few of those items between pre and post-mockup inquiries. Monitoring present position and progress, A/R fuel control, monitoring ground mapping radar, and monitoring flight instruments all demonstrated the identical degree of shift and in the same favorable direction. That is, after the mockup exercise, three boom operators had changed their opinions and thought those tasks could be performed with no training rather than with some training. A majority of boom operators thought the following tasks required at least some training: copying and decoding messages, monitoring PPSN and progress, rendezvous communication, monitoring weather radar, monitoring ground mapping radar, airborne radar approach, map reading, completing the flight log, and computing takeoff and landing data.

As did the pilots and copilots, the boom operators gave very favorable remarks to the mockup evaluation and mission scenario while indicating that they may have underestimated only navigation and rendezvous tasks for relative difficulty.

SECTION IV

DISCUSSION

As stated previously, the tanker mission is quite complicated and, as a result, crew members feel that eliminating the navigator position could be costly in many ways. With a design as represented in the minimum update configuration, they feel that safety could be jeopardized and chances for mission accomplishment would be reduced. Their suggestions to enhance safety procedures and mission accomplishment with a reduced crew complement include not only relocation of present and useful KC-135 avionics hardware, but also significant upgrading of that equipment which has become outdated by advances in technology or has outlived its usefulness altogether. For example, if two items were chosen which would comprise the only two pieces of hardware to be added to the tanker in the event of a reduction of crew size, the pilots and copilots alike would choose the navigation management system and the horizontal situation display. These two pieces of hardware represent a majority of the functions that the navigator now performs and supply all the critical parameters necessary for tanker mission accomplishment.

Although not explicitly stated by the crew members, the reason for the desirability of these particular devices is quite simple. That is, they provide to the pilot and copilot a visual and mental representation of exactly how the aircraft is oriented in space and time. Currently, the navigator is the only crew member who can provide this quick and precise description of aircraft positioning in relation to the flight plan and other aircraft in the formation. Primarily this is so because the navigator works at and updates his information regularly, especially during overwater and high latitude missions.

Within the last several years, advances in computer technology have enabled navigation techniques to become highly automated. In fact, there are several navigation systems currently in use commercially which yield superb space/time orientation. The tanker scenario, however, is vastly different from that of commercial airliners, and the limited capability information displays provided by most commercial off-the-shelf navigation systems are not sophisticated or flexible enough to sufficiently download the tasking of a KC-135 pilot or copilot without a navigator. As some crews emphasized, the result of such a move would be to take one pilot and effectively make him a navigator.

This is perhaps the major reason behind the almost total acceptance by the SAC crews for a navigation system as envisioned in the moderate and major updates. This system could display sequentially as many as six or seven waypoints at one time and was represented as having the storage capacity to "remember" (and display

with a slew switch) an almost infinite number of them. In addition, the system could store the identifiers for all the nav aids in the world, any one of which could be entered as a waypoint in the flight plan through less than ten keypunches. Fuel status was constantly updated by the mission computer, as was the aircraft's present position in relation to the flight plan and waypoint data (estimated time of arrival, time and distance to waypoint), while the flexibility to perform CG computations and calculate take-off and landing data was always there. Holding and rendezvous patterns could easily be programmed in three steps and could be inserted into the flight plan in two or three steps.

While the nav management system provided the mental and sequential image necessary to stay on the flight plan, the horizontal situation display provided the visual image for it. The importance of such a display cannot be overestimated given the fact that a navigator will almost constantly have his charts in front of him and, at the same time, will be relying on radar for weather, formation position, and nav information. In the absence of the navigator, this type of information must be available to both pilots upon demand and this was just one type of format that was selectable. A map could be selected as either north-up or track-up and weather, ground mapping, or beacon radar modes could be overlayed upon the map. Of course, holding and rendezvous patterns could easily be routed around weather cells and the radar sweep control would allow quick determination of distance and heading to any particular target.

An additional plus as far as the pilots were concerned was that both HSDs operated independently so that two different formats could be displayed on the front panel and, at the same time, provided the necessary redundancy should one of the displays fail. Finally, the ability to overlay certain types of radar over a visual rendering of space positioning greatly reduces the amount of around the cockpit scanning that is now necessary. This eliminates the requirement for the pilot to mentally calculate or interpret the relative locations of the flight plan points and the radar returns. For additional assistance, certain other flight parameters are also displayed on the HSD. Thus, instrument monitoring is made much simpler by decreasing the amount of area to be frequently checked.

Investigations of the results of data dealing with other moderate and major update refinements demonstrated that the tanker mission (as performed without a navigator) can be further enhanced through more logical grouping together of certain systems/subsystems displays and controls. The space-saving, solid-state, vertical scale instruments were rated highly by the pilots and copilots not only because of their convictions that such systems would be easier to monitor and see in general, but also because the engine instrument and hydraulic oil quantity and pressure indicators had been consolidated into geographically contiguous areas. The effect of this was again the reduction in the area which needed to be scanned.

Additionally, the inclusion of a caution/warning annunciator panel in the moderate update virtually eliminated the necessity for both pilots to check "behind" them for malfunctions.

The one area where design trades were compromised in comparison to the present-day tanker was on the fuel panel. The importance of a schematic/diagrammatic type approach in designing an alternative fuel panel/switching matrix was underestimated. To paraphrase one copilot, it may be bulky and antiquated, but it's simple to learn, easy to operate, and difficult (if not impossible) to accidentally flip the wrong switches. The fuel-switching matrix did not retain the schematic flow as represented on the old fuel panel and this fact, in conjunction with the poor location of the matrix in the moderate update, yielded heavy criticism from the crews. In discussing the problem, all crew members agreed that as long as some diagrammatic representation was available close to--or overlaid upon--the switching matrix, the fuel panel size could be reduced by utilizing smaller switches and incorporating digital readouts instead of the fuel gauges. It was thought that this avenue would yield a similarly simple and fail-safe fuel panel with significant real estate savings. This approach will be further evaluated during simulation.

In the results section it was pointed out that many crew members thought there would be insufficient time for "see and avoid" in any of the three designs evaluated. Although this finding may have resulted from the fact that the navigator had been eliminated and now all crew members had to assume extra responsibilities leaving insufficient time to monitor outside the cockpit, there may be another, more plausible explanation for this. That is, given the mockup environment (the opaque windshields negated seeing anything outside even if looking in that direction) and the rapid pace of the mission which the experimenters set up, the crews never really had to address the see and avoid issue. Every crew was artificially moved from one high workload segment to another high workload segment with very little time in between. An example of this was the Loring AFB to the United Kingdom fighter deployment which would take seven to eight hours real time, but only lasted approximately two to three hours as a mockup exercise.

This line of reasoning is further substantiated by the workload data resulting from the experiment. It was noted in the results section that the projected workload for both pilots and copilots was very nearly equal for each flight segment across all three design updates. The key word here is "projected". Because the crews were pretending to be flying a mission, and further, were projecting the ease with which that mission could be flown with the particular design in question, it may be reasonable to assume that the resultant workload data is more dependent upon the pace established by the experimenters than the difficulty of flying the mission while utilizing the candidate crew system configurations. This question will be more fully resolved with a closer, more statistically-oriented evaluation of the secondary task data.

As a final issue for review, this discussion turns to the reasons why the pilots (but not the copilots) rated the major update design as being lower than the moderate and minimal updates for "usefulness/necessity in accomplishing the refueling mission". It is believed that this rating resulted solely from "over-sophistication" of the avionics in the major design. Pilots prefer to feel in control of every aspect of flight and, in reality, there must be one person on board the aircraft who does make the final decisions during moments or segments of extremely high stress and workload. Almost without exception, the pilot is delegated that task. This fact is related to the major update in that two of the most significant differences among the three update designs were the caution/warning system and the automatic fuel management system. In the minimum configuration, the caution/warning indicators did not change location from the present KC-135 system, while the moderate design consolidated these indicators onto one panel in easy view of the pilot and copilot. The major design employed an alphanumeric listing panel which would identify and prioritize all failures. Furthermore, emergency checklists could then automatically be presented on the fuel management CDU. Although the system represented in the major update sounds good, the pilots noted in debriefing comments that even though they could direct and override such systems, they preferred to be more involved in those activities. It is likely that such opinions are linked to an initial underlying distrust of automatic systems. In addition, the general consensus among the pilots was that the integrated comm/nav tuners along with the caution/warning prioritization panel were not necessary to accomplish the tanker mission. These facts affected the whole design adversely. It should be noted, however, that the pilots did emphasize that a center panel CRT for weather radar and a fuel management CDU on the aft center console (control stand)--both of which were represented in the major update--were good ideas and helpful in accomplishing the mission, but were not really necessary.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

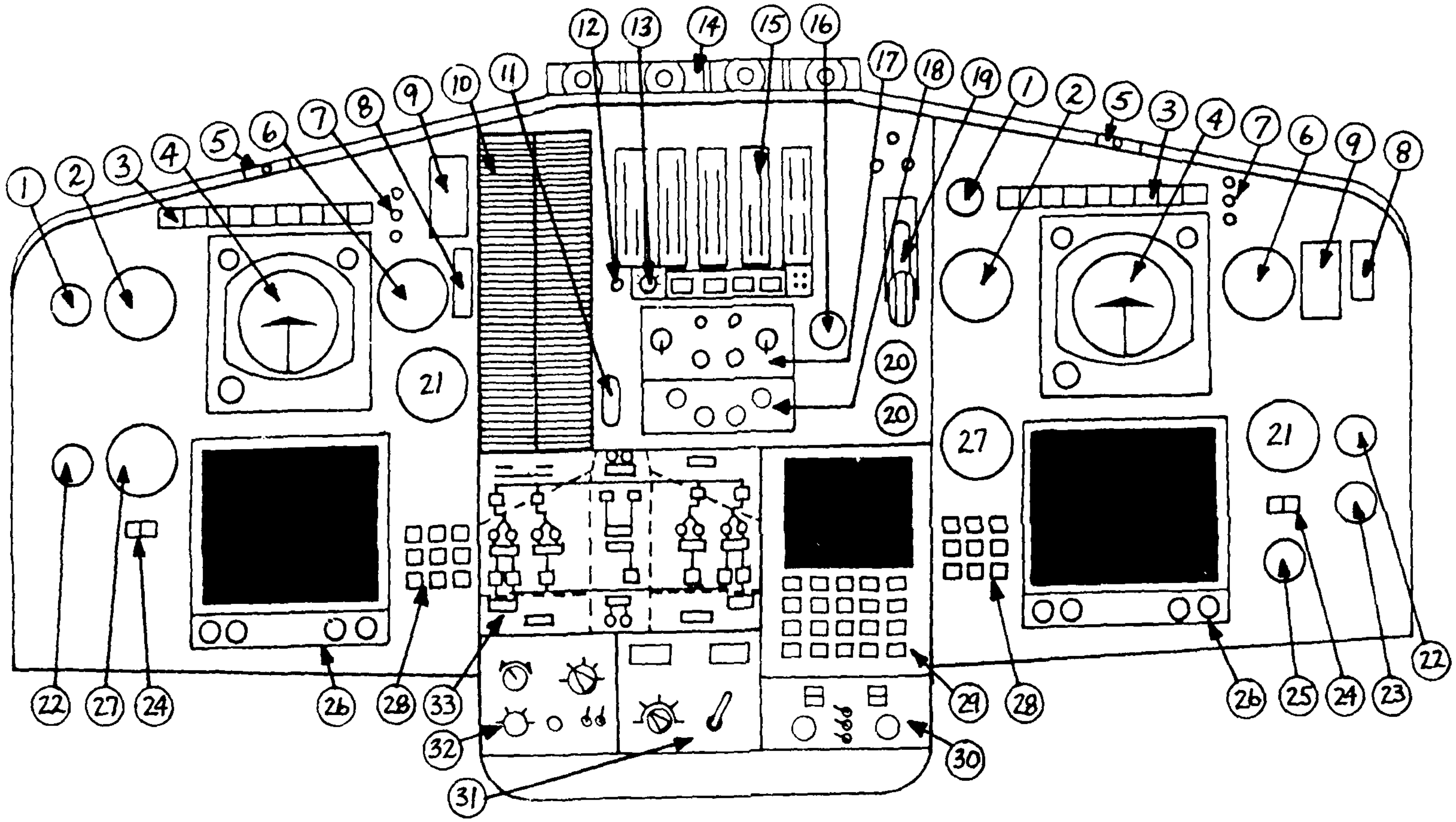
This section defines the capabilities to be met by a two pilot, one boom operator flight crew for the KC-135 based on the results of mockup evaluation.

The mockup study results provided adequate information to define the following "best choice" crew system redesign configuration (Figures 21-26) required to perform the KC-135 tanker mission with a crew complement of two pilots and a boom operator. To test its validity, this design will be evaluated in simulation and further refined. It should be kept in mind that the primary concerns guiding the redesign process were crew complement, workload and mission requirements. These concerns are reflected in the collocation of similar functions, controls and displays, attempting to locate the most critical system information and control within easy access of all flight deck crew members. The less demanding system controls and displays are situated in less critical access locations.

Finally, it should be reemphasized that the goal of the TAACE effort is to specify the criteria necessary for a two pilot, one boom operator flight crew to accomplish the aerial refueling mission. However, in order to evaluate a concept in crew systems design, a piece of hardware which is capable of accurately representing that concept must be analyzed. For that reason, the "composite" design, which is described in detail in paragraphs A through F, will be evaluated during simulation in the respect that its capabilities and their necessity for accomplishing the mission will be determined and not the merits of the actual hardware.

A. PILOTS' FRONT PANEL (Figure 21)

It was considered impractical to optimize the instrument arrangements on the pilots' flight instrument panels because of the design of the control yokes. The hub of the yoke (top of the control column) extends to such a height that the pilots' visibility of their respective flight instrument panels is severely restricted. Ideally, the ADIs and HSI/HSDs should be positioned on the pilots' centerline to eliminate parallax errors. However, these instruments are offset several inches toward the aircraft centerline on both the present KC-135 and this redesign so that the horizontal situation display may be seen by the pilot through the opening in the yoke. Other less critical displays are obstructed by the control column. This offset has the additional undesirable effect of not allowing for duplicate arrangement of instruments on the pilot's and copilot's panels due to lack of appropriate space. This arrangement difficulty is identified later.



* 1) Angle of attack indicator (copilot's location unchanged)
\# 2) Mach/airspeed indicator
3) FD-109 annunciator lights
4) Attitude director indicator
\+ 5) Master caution light
6) Altimeter
\+ 7) Marker beacon lights
\+ 8) Altitude alert lights
\+ 9) Radio altimeter
\+ 10) Caution/warning panel

* 11) Cabin pressure emergency release
\+ 12) Thrust mgt system control
\+ 13) Engine instrument digital readouts and selector
14) Engine fire switches
\# 15) Engine instruments
* 16) Hydraulic quantity indicator
\+ 17) Altitude alert control panel
* 18) Water injection panel
19) Landing gear lever
20) Flap position indicators

21) Vertical velocity indicator
* 22) Clock (also added for copilot)
23) Outside air temperature gauge
\+ 24) INS/AHRS select switch
25) Cabin pressure indicator
\# 26) HSD/MPD
\+ 27) Bearing-distance-heading indicator (BDHI)
\+ 28) HSD mode selector switches
\+ 29) Nav mgt control/display unit #1
\+ 30) INS mode control panel
\+ 31) Radar cursor and doppler controls
\+ 32) Attitude heading reference system control panel
\# 33) Fuel control panel

\+ New hardware, new location
\# New hardware, current tanker location
* Current tanker hardware, new location

Figure 21. Composite Design: Pilot/Copilot Front Instrument Panels and Forward Center Console

1. Pilots' Flight Instrument Panels (Figure 21)

a. Airspeed Indicator (item 2) - Maintained in present baseline location for the pilot and copilot and upgraded to display both mach and airspeed. This unit is CADC compatible with a redundant pneumatic capability. This upgraded instrument reduces required panel space, increases accuracy and efficiency through the CADC and decreases workload by presenting similar information on a single instrument.

b. Mach Indicator - The baseline mach indicator information has been incorporated into the mach/airspeed indicator. Therefore, the baseline indicator is removed.

c. Angle of Attack Indicator (item 1) - Relocated baseline indicator adjacent left of the pilots' mach/airspeed indicator to collocate similar functions which reduces workload and enhances safety. Copilot's indicator is not moved from baseline location due to control column restrictions discussed in paragraph A.

d. Radio Altimeter (item 9) - Relocated adjacent right of the copilot's altimeter and above the pilot's altimeter, while updating to a tape (vertical scale) display. This collocates similar information to reduce workload and enhance safety. The location of the pilot's radar altimeter is not optimized due to control column restrictions discussed in paragraph A.

e. Radio Magnetic Indicator (item 27) - Relocated adjacent left of the pilot's and copilot's HSD and updated to include DME, thus transforming it to a bearing-distance-heading indicator (BDHI). This collocates similar information which helps reduce crew workload.

f. Horizontal Situation Indicator (item 26) - Eliminated and replaced with a CRT display for both pilots which will provide pilot selectable formats and will overlay radar information on a symbol generated map display. The selected overlay of information is independent between the pilot and copilot displays. This increase in information and flexibility (over the HSI) reduces panel space required for radar and reduces chart following requirements while increasing position awareness in relation to navigation fixes, radar ground references, hazardous weather and other aircraft (formation or rendezvous). This reduces pilot workload while enhancing safety. The switching matrices (item 28) for the HSDs are located inboard of each display as described in i below. (The formats which will be available on the HSDs during simulation are presented in Appendix III).

g. Vertical Velocity Indicator (item 21) - Upgraded baseline indicators with CADC compatible VVIs for both pilots in baseline location. This upgrade increases instrument flying accuracy by eliminating lag which in turn decreases pilot workload.

h. Clock (item 22) - Added 8 day hack clock adjacent to the copilot VVI. This unit provides essential information for the copilot during performance of navigational duties. Relocated pilot's clock to adjacent BDHI because of higher priority displays at baseline location.

i. TACAN Select (item 28) - Replaced with a computer/TACAN/VOR navigation mode select switch and relocated adjacent to the inside of each HSD. This location allows the pilots to operate the switches with their throttle hand. This functional necessity is added to provide each pilot the flexibility of displaying computed (INS, doppler, ILS, etc.) course guidance on the flight director (HSD/ADI) or raw data (TACAN, VOR) on the HSD. The nav mode select switches will identify which nav system is driving which HSD bearing pointers and CDI as well as identify which nav system is driving the flight director. This selectable navigation feature reduces pilot workload by adding long-range guidance information to the flight director. The HSD format and other special functions are also selectable through these switching matrices.

j. Marker Beacon Light (item 7) - Replaced with three light displays and located above the barometric altimeters. This collocates similar information during approaches.

k. Altitude Alert Lights (item 8) - These lights are added to operate in conjunction with the altitude alert panel described under "Engine Instrument Panel". The location adjacent the pilot's barometric altimeter and adjacent the copilot's radar altimeter provides similar information to be collocated.

l. INS/AHRS Select Switches (item 24) - These controls are added to work in conjunction with dual INS and the AHRS for redundant capabilities in attitude and heading reference displays. Their location at the lower outside corner of the HSDs is convenient and unobtrusive for physical and visual access by each pilot.

2. Engine Instrument Panel (Figure 21)

a. Engine Instrument Group (item 15) - EPR, RPM, EGT, Fuel Flow, Oil Pressure. This group of instruments remain in baseline location. However, round dials are upgraded to electro-optical, all solid state, vertical scale indicators to reduce required panel space, increase the ease of information interpretation, and centralize similar functional information which in turn reduces crew workload. System information also displayed on tapes that are relocated to become part of this engine instrument group includes the hydraulic pressure indicators (4 each) which are relocated from the pilot's side panel and pilot's instrument panel to a location adjacent and to the right of the engine instrument group (included in item 15, Figure 21). Additionally, if the new engines which are programmed for the KC-135 fleet require oil quantity information to be displayed, vertical scale instruments should also be located on the engine instrument panel.

The Engine Instrument System includes a selectable digital readout (item 13) for each of the parameters (e.g. when EPR is selected, that information for all four engines is displayed simultaneously along with the vertical scale EPR indications). A digital readout can be selected and displayed for EPR, RPM, EGT, fuel flow, oil pressure, hydraulic pressure, and commanded EPR. The Engine Instrument Group also includes a Thrust Management Selector (item 12) located adjacent to the engine digital readout/selector. The thrust management system yields the most optimum engine performance at any particular pressure altitude and outside air temperature. The system accomplishes this in accordance with the particular flight segment in question, such as climb, cruise, or descent. During operation, the pilot would set the mode selector to the applicable condition of flight. At the same time, the aircraft sensors would be determining pressure altitude and outside air temperature. Then, based on these parameters, the thrust management display shows the most efficient EPR command and airspeed settings. This display is collocated with similar functions and is centrally located for easy crew access.

b. Hydraulic Quantity Indicators (item 16) - The baseline hydraulic quantity round dial indicator is relocated from the copilot's instrument panel to a position below the engine instrument group so as to collocate similar type information.

c. Caution and Warning Annunciation Panel (item 10) - Virtually all caution and warning lights are located within a central caution and warning panel which is located adjacent and left of the engine instrument group. This centralizes failure information and locates it in the immediate forward eye reference of each crew member, thereby, enhancing safety and reducing workload.

The panel extends from the top to the bottom left of the engine instrument panel. The cabin pressure emergency release handle is moved lower and toward the center to provide caution and warning panel space. This panel of individual warning lights includes dedicated, annotated caution information as follows:

1) Engine Oil Low Pressure Warnings (4) relocated from pilot instrument panel.

2) Hydraulic Pump Inoperative Warnings (4) relocated from copilot's instrument panel.

3) Hydraulic Overheat Warnings (4) relocated from copilot's instrument panel.

4) Fuel Manifold Low Pressure Warning relocated from fuel panel. The four pump low pressure warning lights will remain on the fuel panel.

5) Switched DC Bus Failure Warning relocated from engine instrument panel.

6) DC Failure Warning added to alert crew to check overhead DC panel for specific failure information.

7) AC Failure Warning added to alert crew to check overhead AC panel for specific failure information.

8) Cabin Pressure Warning relocated from copilot's instrument panel.

9) Cargo Door or Hatch Not Latched Warning relocated from copilot instrument panel.

10) Engine Anti-Icing Indicator relocated from copilots' side panel.

11) O-Inlet Heat Failure Warning relocated from engine instrument panel.

12) Electronic Cabinet Cooling Overheat Warning relocated from navigator's aft panel.

13) IFF Mode IV caution relocated from navigator's aft panel.

14) Copilot's Instrument Power Off Warning relocated from copilot instrument panel.

15) Comparator Warnings relocated from pilots' instrument panels (5).

16) Attitude Gyro Warnings for Pilot, Copilot and Autopilot relocated from pilots' instrument panels (3).

17) Autopilot Disengaged Warning relocated from pilots' instrument panel.

18) RGA Fail Operative Warnings relocated from pilot and copilot instrument panels (2).

19) FD-109 Power Off Warnings relocated from pilot and copilot instrument panels (2).

20) INS Failure Warnings (2) added to alert the pilots that one of the INSs has failed.

21) Radar Pressure Warning moved from nav station to alert the pilots that pressurization for radar components is not within limits.

22) Boom Unlatched Warning added to alert crew that refueling boom is not properly stowed.

23) Center of Gravity Warning added to alert crew that aircraft is approaching center of gravity limitations.

24) Master Caution Lights are added to alert the crew of a system warning announcement which is identified on the central caution and warning annunciation panel. Two master caution lights are located in pilots' glare shield, one in front of the pilot and one in front of the copilot, within easy visual access of the boom operator when he is occupying the jump seat.

25) Leading Edge Flap Extended Warning added to provide an indication when the leading edge flaps are not fully extended and the throttles are advanced to nearly open when the aircraft is on the ground.

26) INS Overheat Warnings (2) added to indicate an over-temperature condition in the INS which may save the set from complete failure providing adequate corrective action is taken.

27) Mission Computer Failure Warnings (2) added to indicate that one or the other mission computers have malfunctioned.

28) INS Different By 10 NM Warning added to alert the pilot that the lateral positions indicated by the two INSs vary by 10 nautical miles.

29) AHRS Failure Warning added to indicate that the attitude and heading reference system has failed.

30) Doppler Memory Malfunction added to alert the pilot that the doppler system is malfunctioning.

31) APU Door Open Warning added to alert the pilot that the APU door in the cabin is not closed.

32) Battery Charge Transformer-Rectifier Warning added to alert the pilot that this system has malfunctioned.

33) Fuel Dump Warning will illuminate during fuel dump operations.

34) Compare Attitude Warning will illuminate when the pilot and copilot attitude indicators differ by more than 4°.

d. <u>Destination Indicator</u> - This indicator has been removed. The information provided to the crew by this indicator has been incorporated into the navigation management control/display unit which is discussed later.

e. <u>Landing Gear and Wing Flap Panel</u> (items 19 and 20) - The panel satisfies mission requirements in the baseline configuration. However, when the gear handle is down, the handle interferes with

visual access to the nav management CDU located on the old fuel panel, therefore it is shortened. The landing gear and wing flap panel includes:

1) Landing Gear Handle
2) Wing Flap Indicator
3) Landing Gear Indicator Panel including Landing Light Switches

f. Water Injection Panel (item 18) - Relocated to the lower center portion of the engine instrument panel from the copilot's instrument panel to provide required space on copilot's panel for higher priority displays. In addition, this location provides improved crew access.

g. Altitude Alert Panel (item 17) - Added to the engine instrument panel, adjacent and above the water injection panel, within easy reach of each pilot and within good visual access of all flight deck crew members. The altitude awareness that was previously provided by the navigator to satisfy safety requirements will be provided with the altitude alert system.

3. Forward Center Console (previously identified as the Fuel Panel), forward of the throttle quadrant (Figure 24)

a. Fuel System Controls (item 33) - The fuel panel has been redesigned to a smaller size unit with increased capability. It consists of the same number of pump switches, valve switches and quantity indicators as the present panel, including the upper deck tank. The quantity indicators are digital readouts rather than round dials to conserve space and provide the information more readily. A line drawing of the fuel routing possibilities is incorporated on the panel. The capabilities of the panel are increased by providing an aircraft center of gravity display and the boom engaged light. These are incorporated into the fuel panel, since their functions are directly related to the fuel system, which in turn helps to reduce crew workload.

b. Nav Management CDU #1 (item 29) - This unit is located on the right side of the fuel panel on the forward center console. The unit, used primarily by the copilot but accessible by both pilots, consists of a CRT and an alphanumeric keyboard. It provides the interface between the pilots and the navigation/mission computers and is used primarily to control and display navigation information. For example, this unit is used to make inputs to the inertial navigation systems rather than using a dedicated INS control head. An identical nav management CDU with the same capabilities is located aft of the throttle quadrant to provide increased flexibility and redundancy.

c. Radar Cursor and Doppler Control Panel (item 31) - Located on the lower center portion of the forward center console.

This unit is added to increase the flexibility of the navigation management system by providing a cursor for the radar display. This allows ground mapping fixes to be used for updating the navigation system and air alignment of the INS. In addition, it controls the mode and power for the doppler system, which is relocated from the nav station and is within easy access of both pilots. It is upgraded to provide state-of-the-art doppler navigation.

d. INS Power and Mode Control Panel (item 30) - This added unit accomodates a fail passive dual INS and is located on the lower right portion of the forward center console. It combines the power, mode and function control for both inertial nav systems into one panel.

e. AHRS (Attitude Heading Reference System) Control Panel (item 32) - This system replaces and updates the N-1 and J-4 heading system as well as the pilots' attitude reference system. Its improved performance enhances mission accuracy and the centralized location allows improved crew access.

B. OVERHEAD PANEL (Figure 22)

Centralized access to the subsystems control for the crew remains a driving workload concern when the navigator is removed, primarily because when one crew member becomes overloaded, other crew members can assume the overload. The overhead panel is reconfigured and generally upgraded except for the baseline light control panels (items 2 and 5), and the flight director control panels (item 13). The cabin pressurization/air conditioning panel (items 1 and 23) and the electrical control panel (item 20) were rearranged to provide more overhead panel space for controls and displays requiring a central location accessible to all crew members.

1. Radar Pressure Control Panel (item 22)

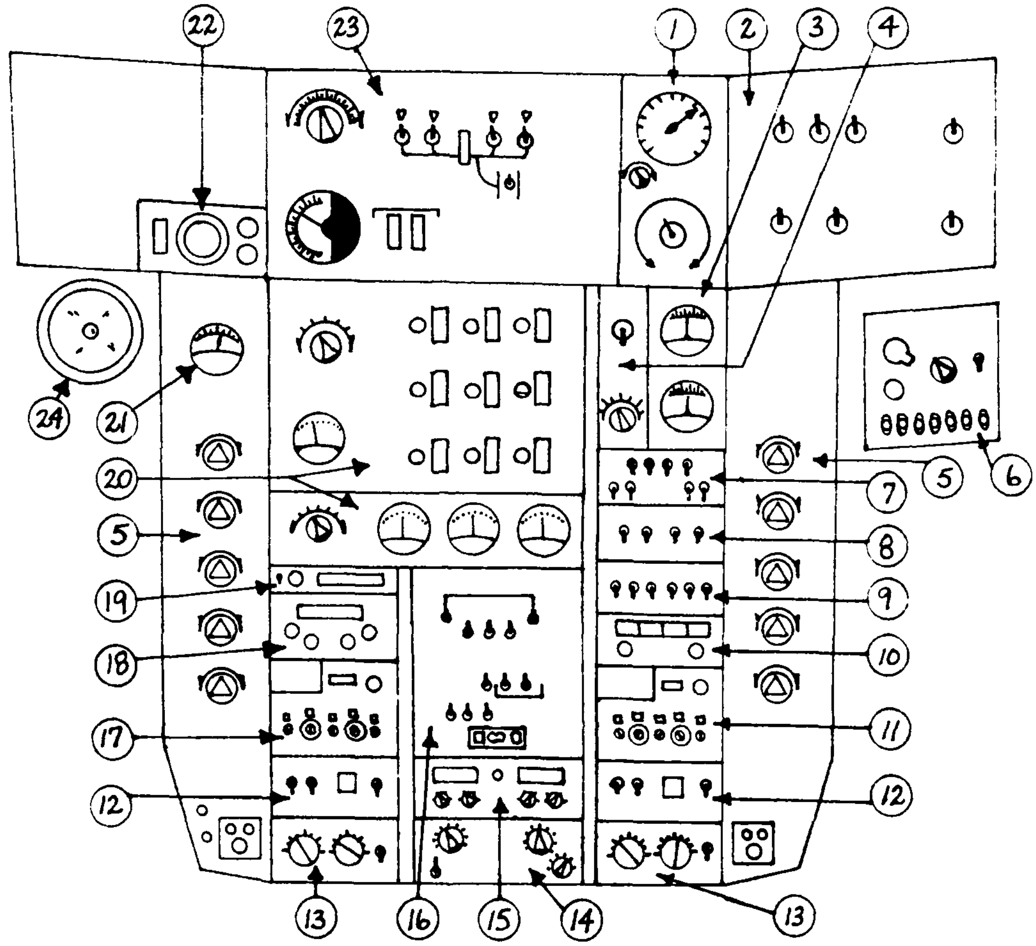
This baseline unit is relocated from the navigator's station to the top left overhead extension panel. This location allows crew control and monitoring of radar system pressure when the pressure exceeds its limits as indicated by the caution and warning system.

2. APN 69 Beacon Control Panel (item 6)

This baseline unit is relocated from the navigator's station to a position above the copilot's seat and to the right of the overhead panel. Since this panel is essentially a "set and forget" item, its location is lower priority, while still crew accessible.

3. Warning Bell, Cockpit Speaker, and TACAN Antenna Control Panel (item 19)

The baseline panels are reduced in size and incorporated into one panel which is moved to the left and center of the overhead panel. This location is slightly lower priority but still crew accessible.



1) Cabin pressure controllers
2) Light control panel (exterior)
* 3) Volts and cycles indicators
* 4) External power control
5) Light control panel (interior)
* 6) APN-69 beacon control panel
\+ 7) Hydraulic control panel
\+ 8) Instrument power control panel
\+ 9) Anti-ice control panel
\+ 10) VHF comm control panel
11) UHF #2 comm control panel
12) Rotation go-around control panel
13) Flight director control panel
\+ 14) Radar control panel
* 15) VHF nav #1 & #2 control panel
16) Autopilot control panel
17) UHF #1 comm control panel
* 18) HF comm control panel
\+ 19) Warning bell, loudspeaker, and TACAN antenna control panel
20) Electrical control panel
21) Battery charging ammeter
* 22) Radar pressurization control panel
23) Air-conditioning control panel
24) Speaker

\+ New hardware, new location
* Current tanker hardware, new location

Figure 22. Composite Design: Overhead Panel

4. Hydraulic Control Panel (item 7)

This panel is added to centralize hydraulic pump switches (from the pilot's side panel) and valve controls (from the copilot's instrument panel). The location of the right center area of the overhead panel is medium priority with fair crew accessibility.

5. HF Comm Radio Control Panel (item 18)

The baseline panel is moved from the copilot's side panel to the lower left center of the overhead panel, which allows fairly good crew access.

6. #1 and #2 UHF Comm Control Panels (items 17 and 11)

The baseline panels were relocated slightly forward to improve crew access.

7. Instrument Power Panel (item 8)

The additon of this panel provides collocation of the copilot's instrument power switch (from the copilot's instrument panel), the battery switch (from the engine instrument panel), IFF antenna switch (from the nav station), the remote heading slew switch (from the overhead panel) and the HF transfer switch (from the copilot's side panel). The panel is located on the right center area of the overhead panel, which allows fair crew access.

8. Anti-Ice Control Panel (item 9)

This panel is relocated from the copilot's side panel to the right center area of the overhead panel with fairly good crew access. The control panel is modified to allow collocation of similar functions which include switches for "Q" inlet heat and electronic cabinet cooling.

9. VHF Comm Control Panel (item 10)

This panel is added to accommodate the communications update required for the KC-135. The location on the right center area of the overhead panel allows good crew access.

10. VHF Nav #1 and #2 (item 15)

Relocated slightly aft to allow space for higher priority panel.

11. APN-59 Radar Control Panel (item 14)

The baseline panel is redesigned and relocated from the navigator's station to the forward center area of the overhead panel to accommodate higher priority crew access.

C. AFT CENTER CONSOLE (Figure 23)

The baseline KC-135 control stand is modified to accommodate several controls and displays aft of the throttle quadrant. This area is expanded from one to two standard widths and extended slightly in length. In order to utilize this space, several controls had to be relocated as described in this section. This aft center console is high priority crew access area.

1. Wing Flap Control (item 13)

This control is moved forward to clear the aft center console area and to be in line with the throttle controls. In order to relocate to this position, the copilot's radar scope was removed. The scope information is displayed on the pilots' HSD, described in paragraph A of this section.

2. Warning Horn Cutout Switch (item 11)

This switch is relocated to clear the aft center console area. Its new location is on the vertical shelf aft of the throttle quadrant.

3. Rudder Power Switch (item 14)

This baseline switch is relocated to clear the aft center console. Its new location is on the vertical shelf aft of the throttle quadrant.

4. Autopilot Control Head (item 3)

This unit is modified to a low or relatively flat profile that does not extend above the level of the aft center console. This modification is necessary to clear the vertical shelf aft of the throttles.

5. Engine Start Selector Panel (item 2)

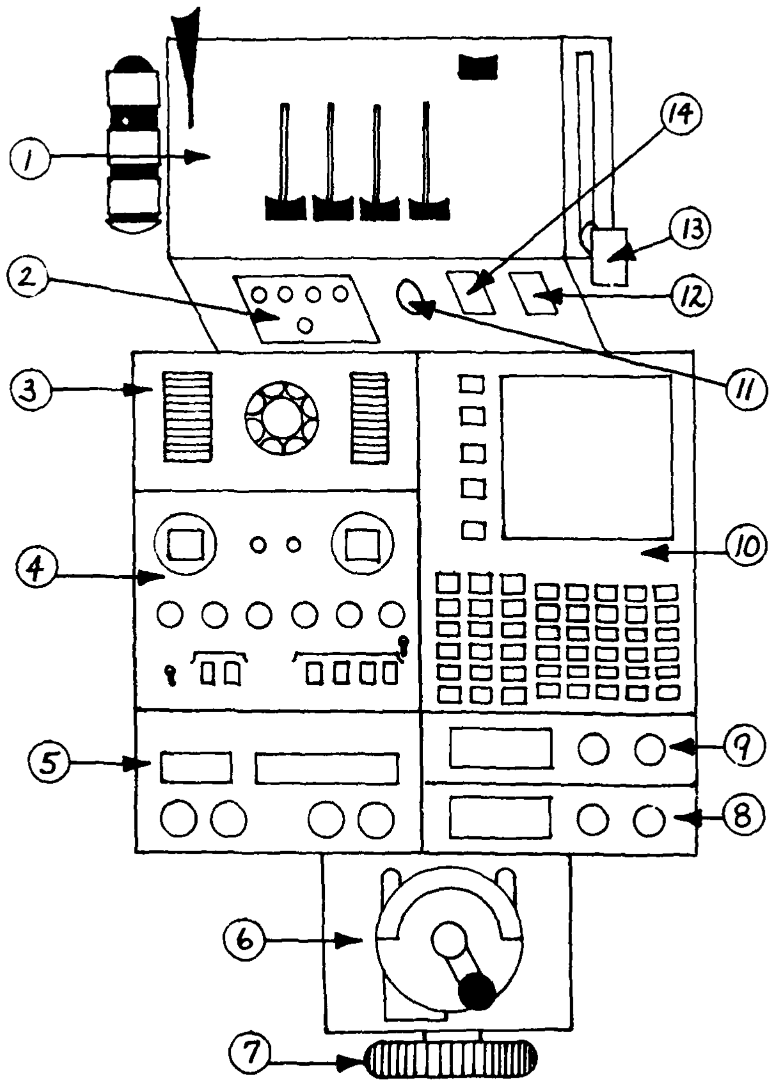
The panel is relocated from the pilot's instrument panel to the vertical area immediately aft of the throttles. This location allows very good crew access. The panel is slightly modified with switch protectors to avoid inadvertent switch actuation.

6. IFF/SIF Control Panel (item 4)

The baseline panel is relocated from the navigator's station to the aft center console. This provides very good crew access.

7. TACAN #1 and #2 Control Panel (items 8 and 9)

The #1 control is relocated from the overhead panel to the aft center console. The #2 TACAN is added capability. In addition, both units are air-to-air and air-to-ground capable. The new location provides good crew access.



1) Throttle quadrant	+ 8) TACAN #1 control panel
* 2) Engine start switches	+ 9) TACAN #2 control panel
* 3) Autopilot controller	+ 10) Nav mgt control/display unit #2
* 4) IFF/SIF control panel	* 11) Gear horn cutout switch
+ 5) ADF control panel	* 12) Stab trim cutout switch
* 6) Rudder trim	* 13) Wing flap control
* 7) Aileron trim	* 14) Rudder power cutout switch

+ New hardware, new location
* Current tanker hardware, new location

Figure 23. Composite Design: Aft Center Console

8. Nav Management CDU #2 (item 10)

This CDU is added for nav management, primarily to be used by the pilot or boom operator but is also accessible to the copilot. Its functions are identical to those described in paragraph A.

9. ADF Control Panel (item 5)

Navigation capability added primarily for use outside CONUS. Panel location provides good crew access.

D. PILOT SIDE PANELS (Figure 24)

The pilot and copilot side panels have been cleared of several controls/displays i.e. (1) hydraulic control panel, (2) anti-ice control panel, (3) HF radio panel and (4) compass control panel. The rationale for relocation of each side panel C/D is described elsewhere in this paper, but in general, the controls and displays that are cleared from the side panels were relocated to allow their access by other crew members.

1. Interphone Control Panel (item 2)

AIC-18 interphone control panels replace AIC-10 controls for each pilot. This decreases pilot workload by providing each pilot with individual audio level control for each radio receiver. The interphone control panel for the boom operator at his jump seat is also replaced with an AIC-18 with the advantages as described for the pilots.

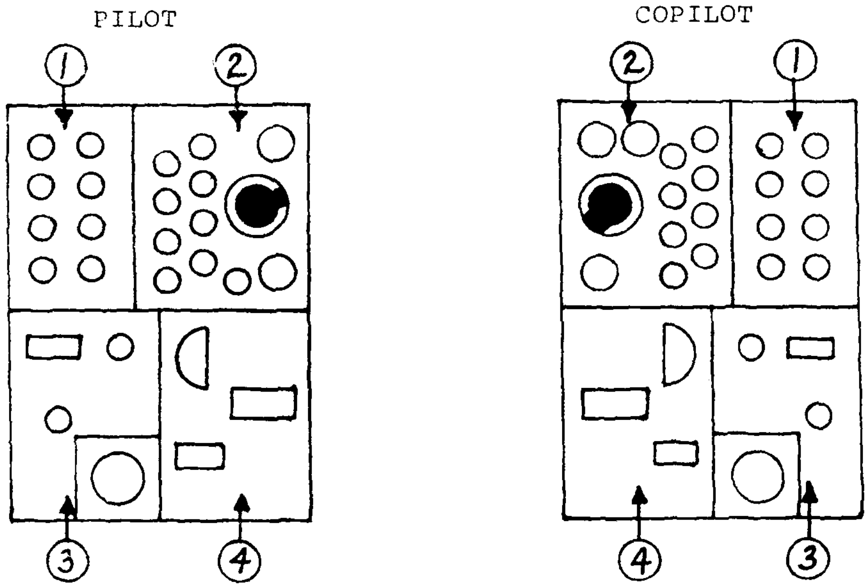
The remaining items on the pilots' side panels (oxygen regulators, etc.) on Figure 24 are slightly modified from baseline.

2. Other Interphone Control Panels

The interphone control panels (AIC-10s) at the navigator's interphone station and the rear seat interphone station on the flight deck (formerly occupied by the boom operator) are also replaced with AIC-18 interphone panels. The advantages are in individual audio level control for each receiver.

E. FORWARD BOOM STATION - FORMERLY THE NAVIGATOR'S STATION

The baseline navigator's station will remain physically intact. The avionics may be removed. The baseline crew seat that serves this station is modified and mounted on a track so that the crew seat can easily be positioned at either the nav station or between the pilots' seats facing the aft center console. This modification will allow the boom operator (during the time he spends on the flight deck) to help manage paperwork, nav charts, monitor aircraft position, communications and perform the duties of a positive control crew member at the nav station. This arrangement also allows



\# 1) Nav monitor panel
\# 2) AIC-18
* 3) Oxygen hose, dimmer,
oxygen quantity,
lamp receptacle
\# 4) Oxygen regulator

\# New hardware, current tanker location
* Current tanker hardware, new location

Figure 24. Composite Design: Pilot/Copilot Side Panels

the boom operator to interact with the pilots from a "middle seat" position at the aft center console. From this position, the boom operator may monitor communications, outside watch, aircraft subsystems, takeoff/landing data (from #2 nav management CDU), assist with the checklists, and perform see-and-avoid duties. To support the new forward boom operator's station, the following reconfiguration is required:

1. Forward Panel of the Previous Nav Station (Figure 25)

The avionics to support the boom operator at the nav station are all arranged on the forward two grid sections (two standard widths) of the navigator's panel.

a. Accelerometer (item 1) - Relocated baseline unit at this low priority location on forward grid. Data does not support the inclusion of this information on any forward instrument panel since it is used only for historical purposes.

b. Ciphony Control Panel (item 2) - Relocated baseline unit from overhead panel to this forward grid location. Good access by boom operator for this rarely used system.

c. HF Transfer and INS Selector Panel (item 3) - This panel is added to allow HF comm radio control at either the overhead panel or at this forward grid location. The INS selector allows the selection of either INS platform to feed the INS control panel. Location allows good access by boom operator.

d. HF Comm Panel (item 4) - Relocated to this forward grid location to allow the boom operator easy access of HF control, assuming he will have increased responsibility for HF while he is on the flight deck.

e. Oxygen Control Panel (item 5) - Relocated from aft nav panel to this forward grid location for quick access by the boom operator and convenient hookup for mask storage.

f. Light Controls (item 6) - These controls are added to give the boom operator lighting control of the forward boom station. Their location in the upper area of the second forward grid allows good access by the boom operator.

g. INS CDU (item 7) - The INS CDU is added to allow the boom operator access to aircraft position and other nav information. It also serves as a redundant INS control head for either INS platform in case of nav management CDU failure. The location in the center of the second forward grid allows good access by the boom operator.

h. AIC-18 and Nav Monitor (items 9 and 8) - As previously discussed in paragraph D, the AIC-10 is replaced with an AIC-18 at

AD-A088 034 BUNKER-RAMO CORP WESTLAKE VILLAGE CALIF ELECTRONIC --ETC F/G 1/2
TANKER AVIONICS/AIRCREW COMPLEMENT EVALUATION (TAACE). PHASE 0.--ETC(U)
MAY 80 G J BARBATO, R P MADERO, G A SEXTON F33615-78-C-3614

UNCLASSIFIED AFWAL-TR-80-3030-VOL-1 NL

2 OF 2
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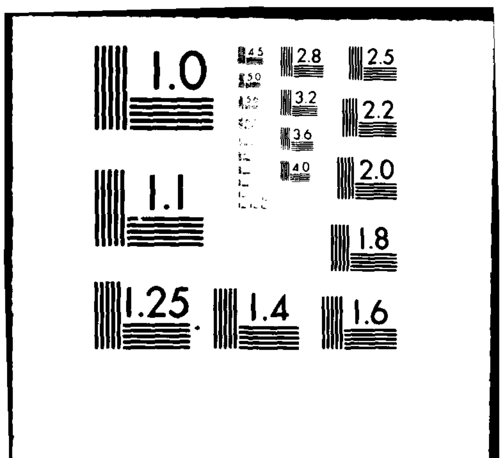
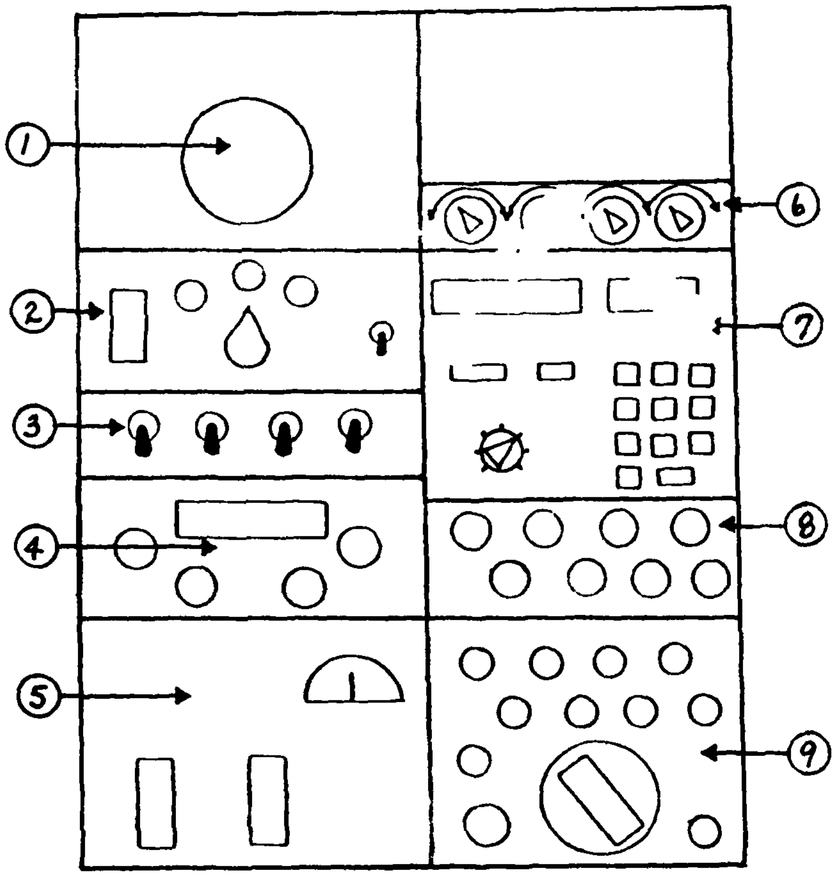


MICROCOPY RESOLUTION TEST CHART



* 1) Accelerometer
* 2) Ciphony control panel
+ 3) HF transfer and INS selector switches
* 4) HF comm control panel
+ 5) Oxygen control panel
+ 6) Light controls
+ 7) INS control/display unit
+ 8) Nav monitor panel
+ 9) AIC-18

+ New hardware, new location
* Current tanker hardware, new location

Figure 25. Composite Design: Forward Boom Operator Station

both this station and at the present IP jump seat station between the pilots' seats. The comm monitor relocation on Figure 25, is in position for highest priority access for the boom operator. The baseline communication unit between the pilots' seats remains in the baseline location (not shown in figures).

F. AFT BOOM OPERATOR'S PANEL (Figure 26)

The evaluation of the updated boom operator's panel produced a "mixed bag" of data. The reconfiguration presented for mockup evaluation was either inadequate or not required. Since the subject data did not provide a clear resolution to the question of a requirement to update the boom operator's station, a redesign will be evaluated during simulation. The proposed redesign will provide the boom operator with forward and aft AR pump control, fuel transfer information and limited fuel quantity information. Only the items changed from the baseline (current) KC-135 are discussed below.

1. Communication Panel (not pictured)

The AIC-10 is upgraded to an AIC-18 as previously discussed. The baseline location remains unchanged (just left of the emergency override switch panel).

2. Circuit Breaker Panel (not pictured)

The baseline circuit breaker panel is a high priority, easy access area. Therefore, the circuit breakers are relocated to a space behind the jack shaft and under the instructor boom operator platform. This clears the baseline panel for higher priority control arrangement.

a. Nacelle Illumination Switch (item 15) - Relocated from center panel to the upper portion of the baseline circuit breaker panel.

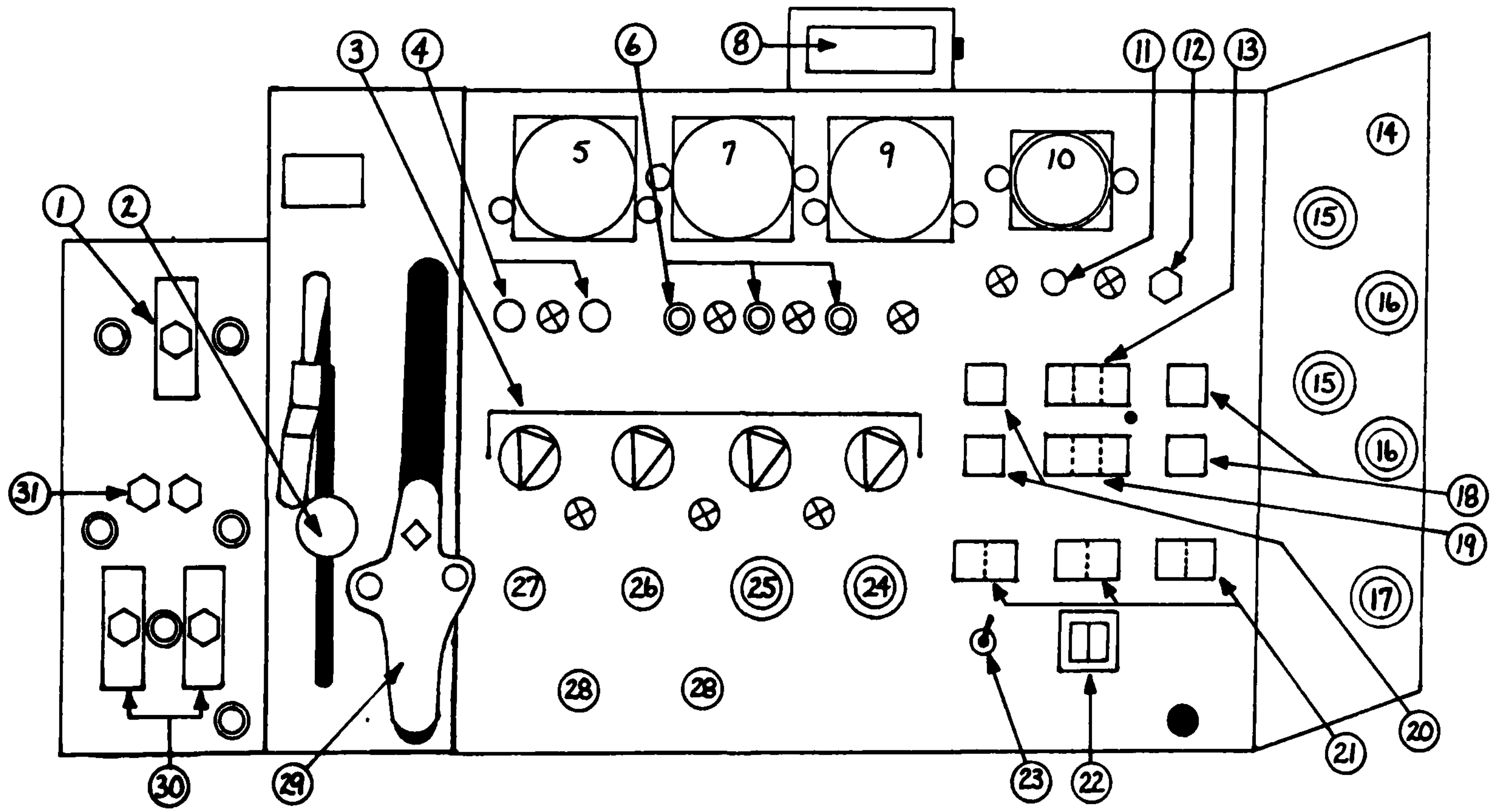
3. Center Panel (Figure 26)

a. Boom Marking Illumination Controls (item 28) - Relocated from the rand hand side of the center panel to the left hand side of the center panel.

b. Director Lights Ground Test Switch (item 26) - Relocated from the lower right center panel to the center of that panel.

c. AR Pump Switches (items 18 and 20) - The four arming type switches are added to this easy access area. These arming switches work in conjunction with stop-start actuation switches which are added to the boom telescope lever (item 29).

d. Fuel Quantity Indicators (item 21) - The three indicators are added to the right center panel to provide necessary fuel quantity information to the boom operator. This digital information is repeated from the forward fuel panel.



1) Emergency override switch
2) Boom hoist lever
3) Pilot director lights controls
4) A/R system test/reset switches
5) Azimuth indicator
6) Contact signal lights
7) Telescoping indicator
+ 8) Fuel transfer indicator (per receiver)
9) Elevation indicator
10) Signal coil voltmeter
11) Signal coil test switch
12) A/R master switch
+ 13) Fuel transfer indicator (per mission)
14) Window defrost switch
* 15) Nacelle illum controls
16) Panel lights controls
17) Compartment lights controls
+ 18) Aft body pump switches
+ 19) Fuel flow indicator
+ 20) Forward body pump switches
+ 21) Fuel quantity gauges
+ 22) Offload selector
+ 23) Auto/manual select switch
24) Boom nozzle illum control
25) Under body illum control
* 26) Director lights ground test
27) Telescope at disconnect switch
* 28) Boom marking illum controls
# 29) Boom telescope lever
30) Ground test switches
31) Pilot director lights switches

+ New hardware, new location
# New hardware, current tanker location
* Current tanker hardware, new location

Figure 26. Composite Design: Aft Boom Operator Station

e. Fuel Flow/Transfer Indicator (items 19 and 13) - The indicator is added to the right center panel to provide offload fuel flow rate and total fuel transferred. A push-to-reset button works in conjunction with the total fuel transferred indicator. The added reset button is located just below the fuel transfer indicator.

f. Individual Fuel Transfer Indicator (item 8) - The indicator is added to the top of the center fuel panel to provide fuel transfer information per receiver. A push-to-reset button is located on the right side of the indicator.

g. Offload Selector (item 22) - The selector is added to the lower right of the center fuel panel to provide pre-selected fuel transfer amounts and automatic shut-off if the auto-manual select switch (item 23) is in the "auto" position.

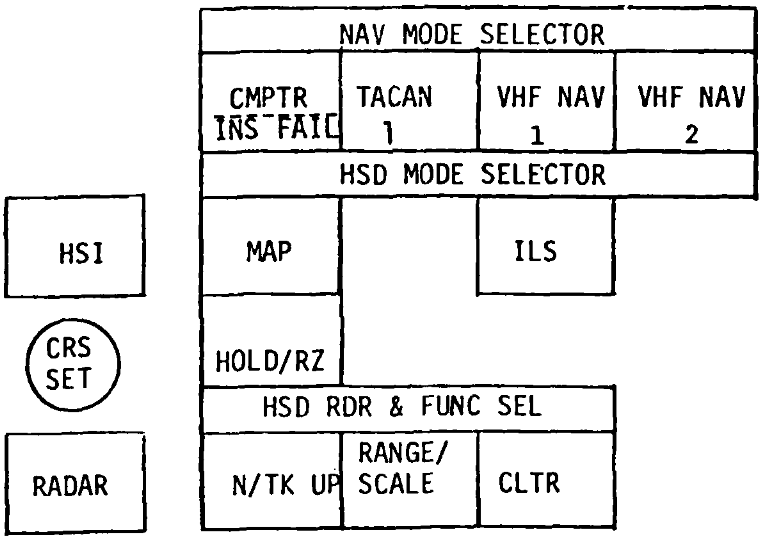
h. Auto/Manual Select Switch (item 23) - The switch is added to the lower right of the center fuel panel and its function is described in paragraph g.

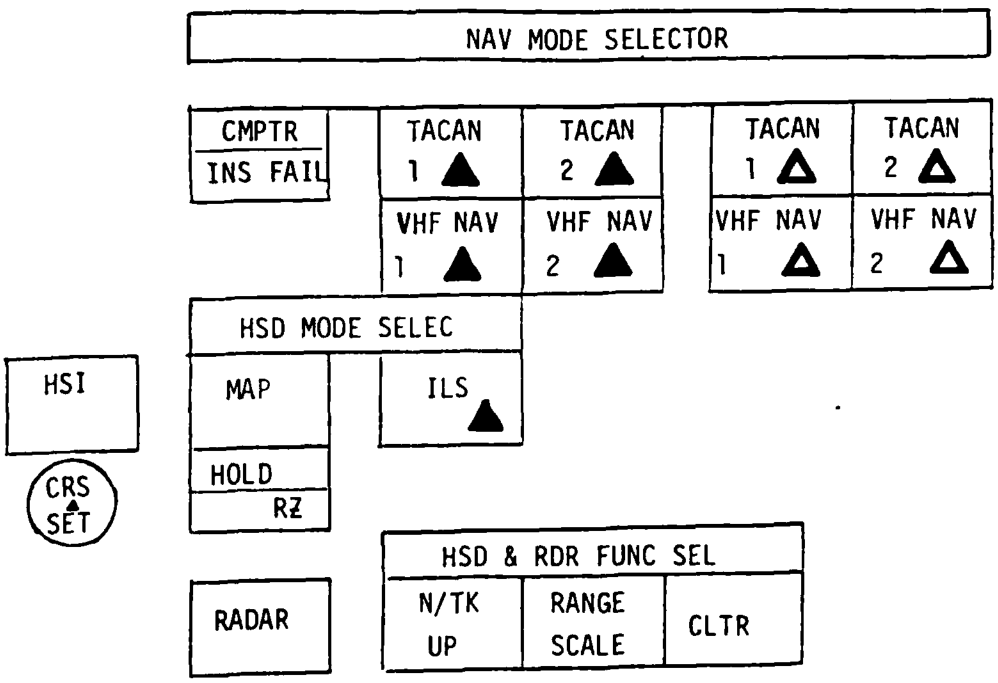
APPENDIX A

Sample HSD Formats

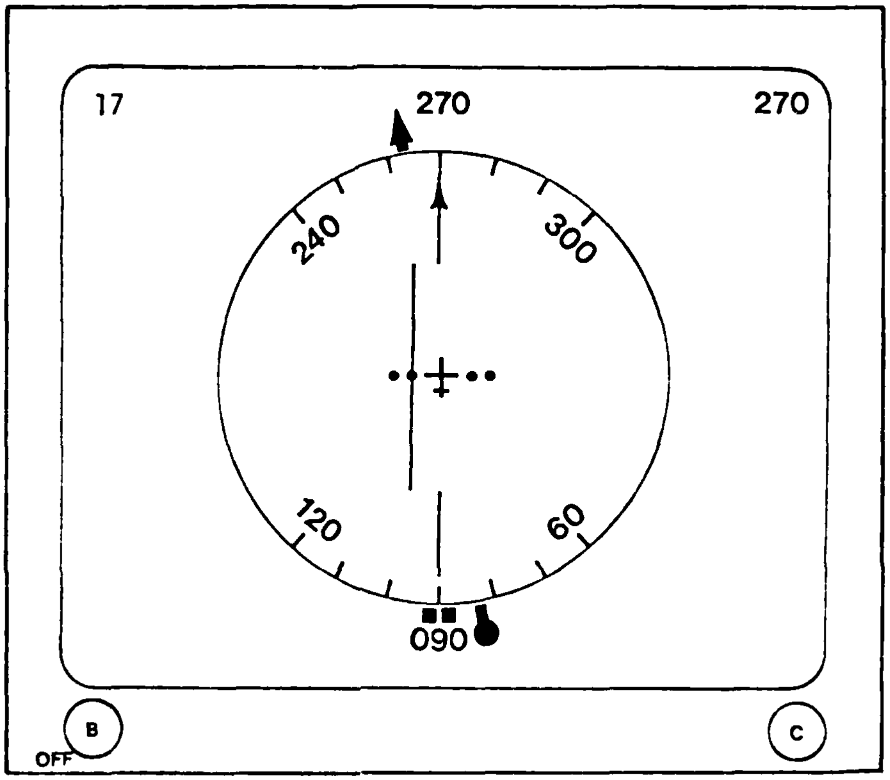
-- HSD Switching Matrix --

Moderate Update





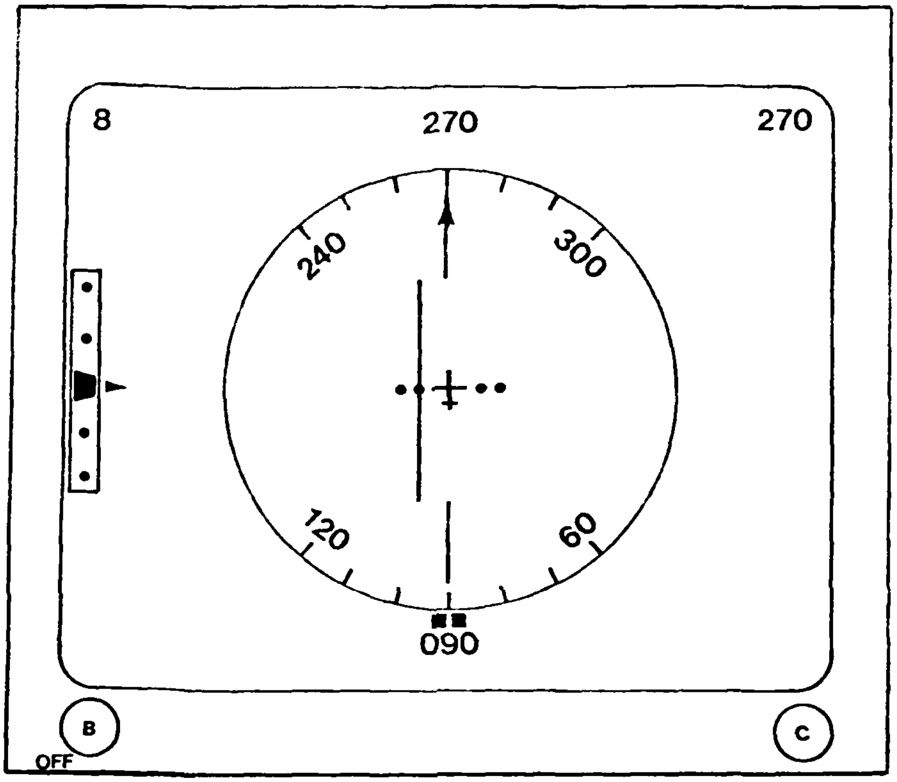
Major Update



-- HSI Format --

Computer or TACAN Nav Mode

(Moderate and Major Update)

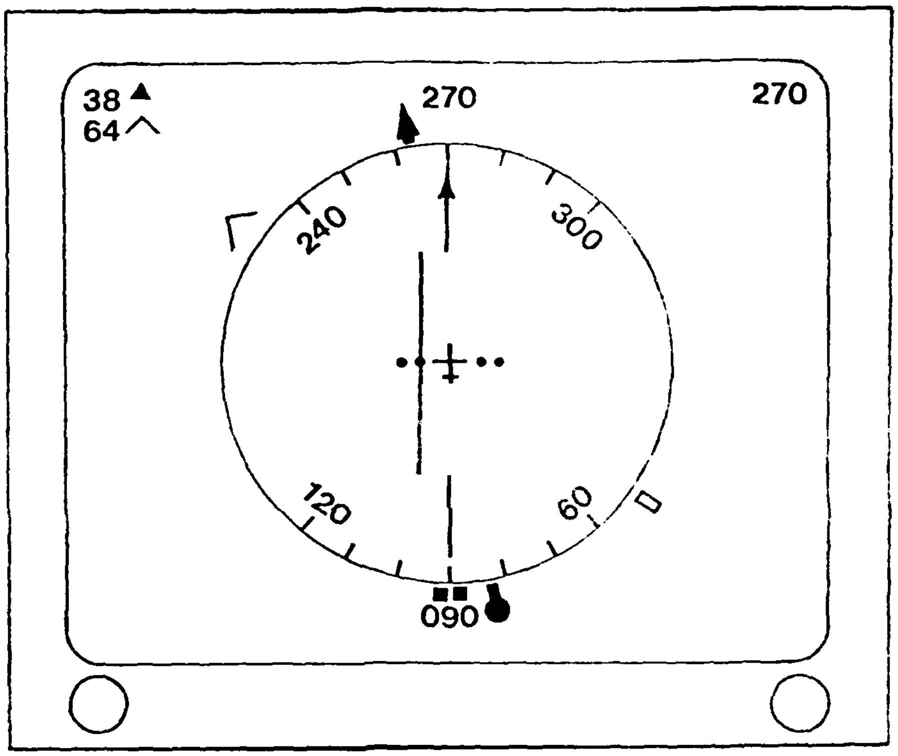


-- HSI Format --

ILS Nav Mode

Moderate Update

(Note: Glide slope indicator, but no bearing pointer)

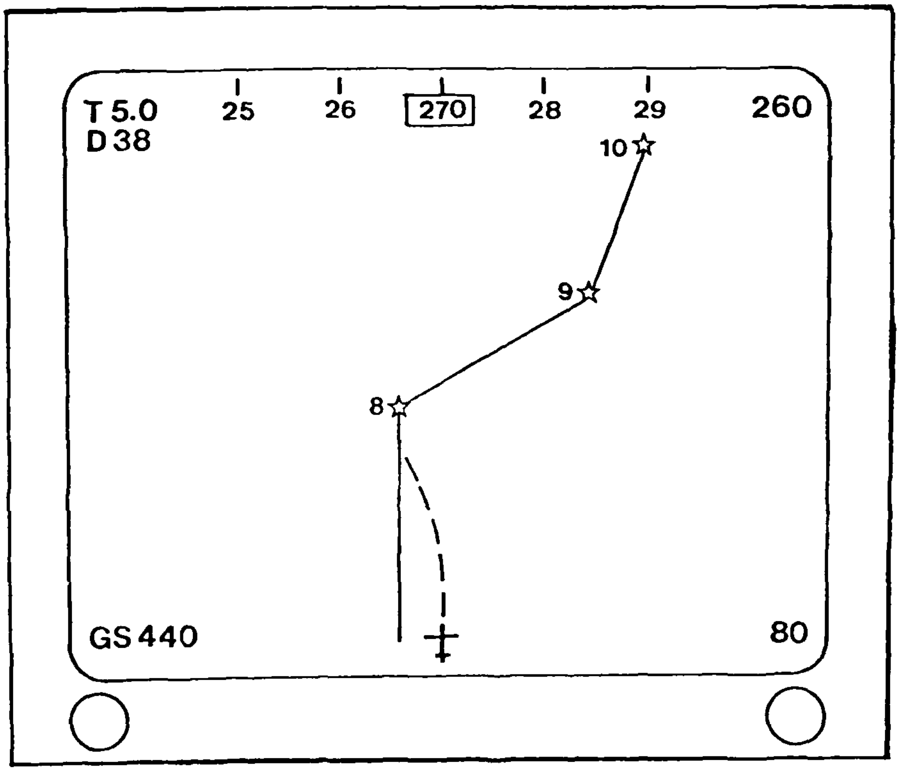


-- HSI Format --

Computer and TACAN Nav Mode

Major Update

(Note: Dual bearing pointers and DMEs)

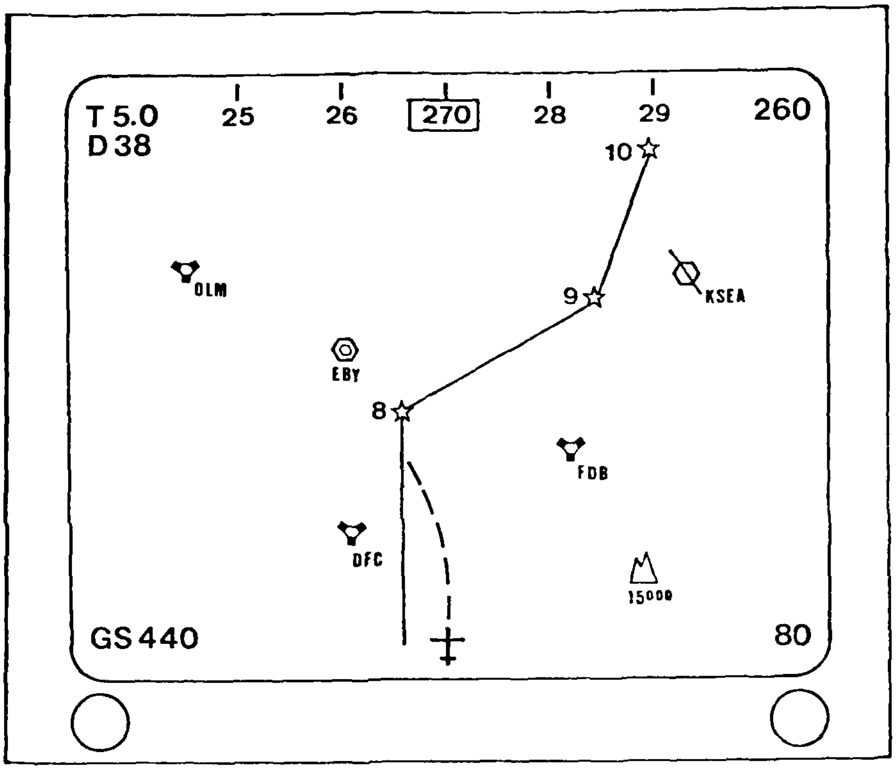


-- Map Format --

Computer Nav Mode/Track-up Presentation

Moderate and Major Updates

(Note: Aircraft position predictor symbology)

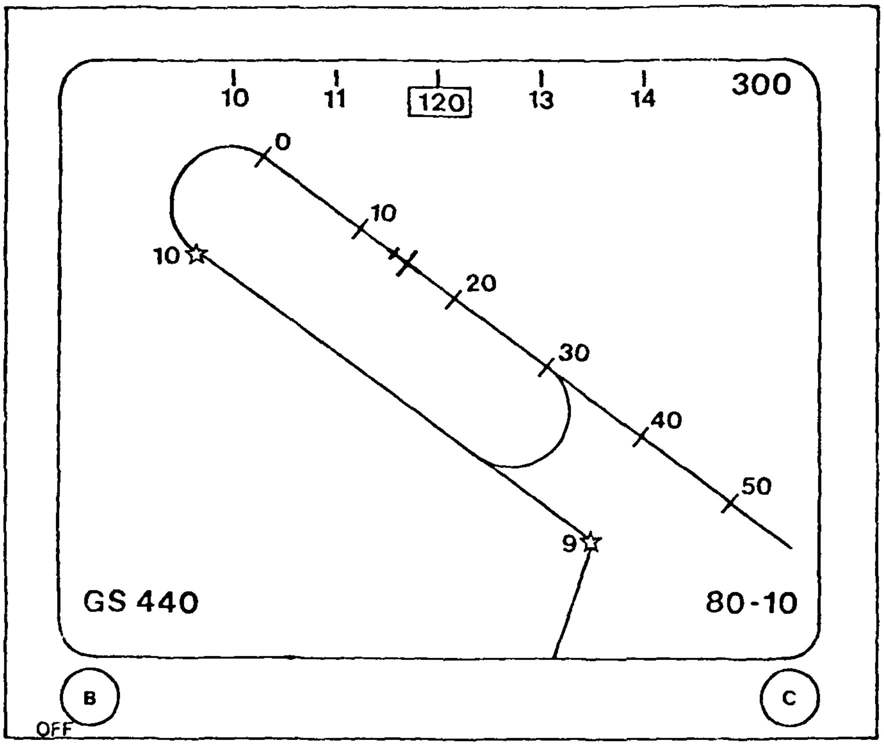


-- Map Format --

Computer Nav Mode/Track-up Presentation

Moderate and Major Updates

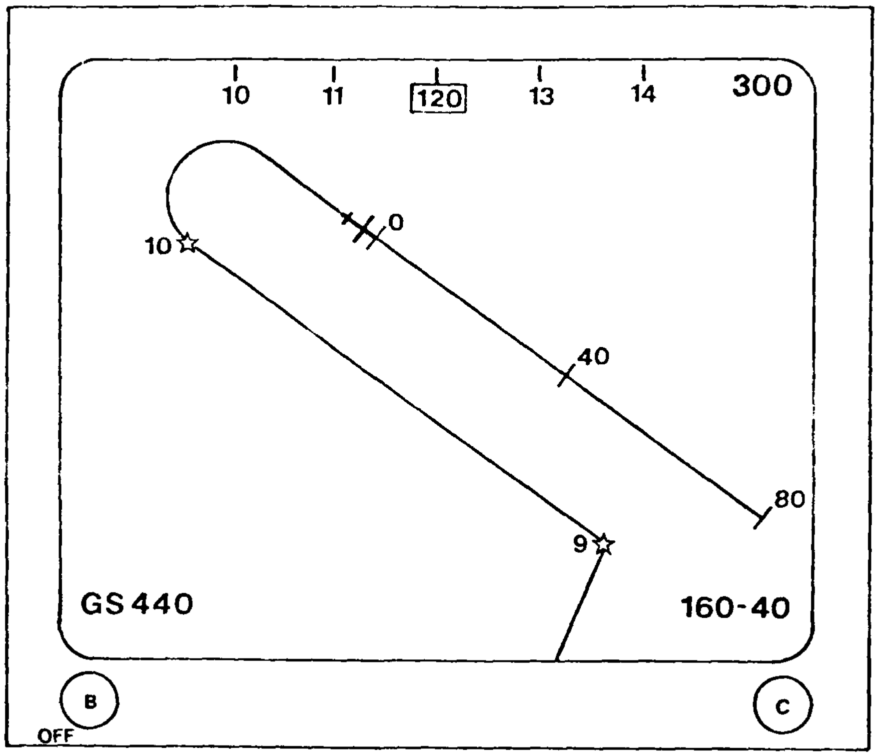
(Note: Large amount of clutter and other symbology)



-- Holding Pattern Format --

Computer Nav Mode/North-up Presentation

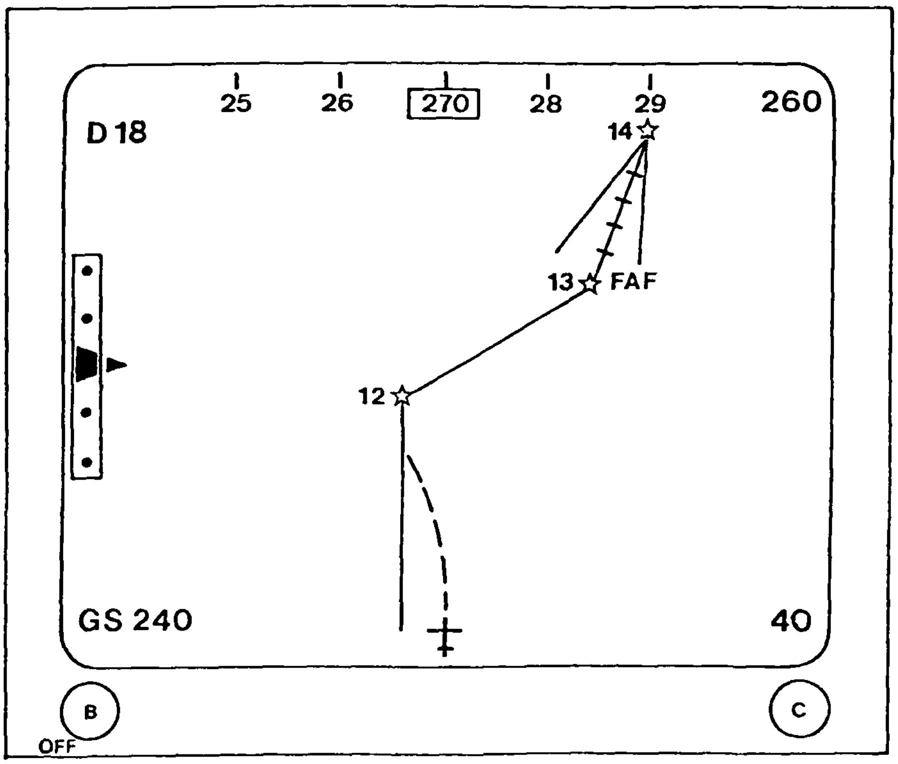
Moderate and Major Updates



-- Air Refueling Rendezvous Format --

Computer Nav Mode/North-up Presentation

Moderate and Major Updates

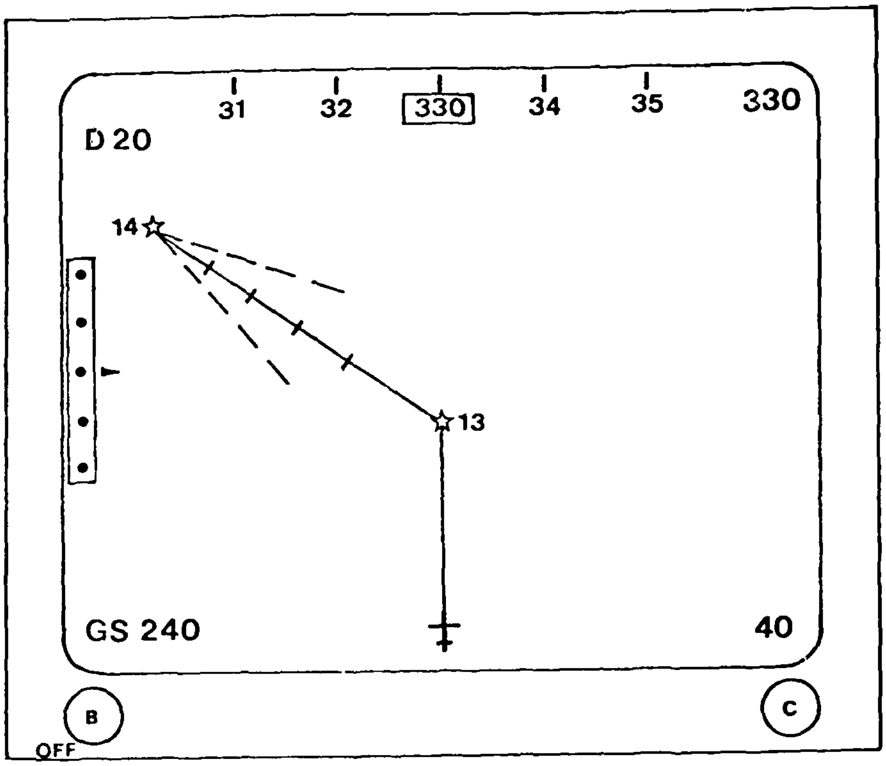


-- ILS Map Format --

Computer Nav Mode/Track-up Presentation

Moderate and Major Updares

(Note: Aircraft approaching airfield/Range: 40 mi)

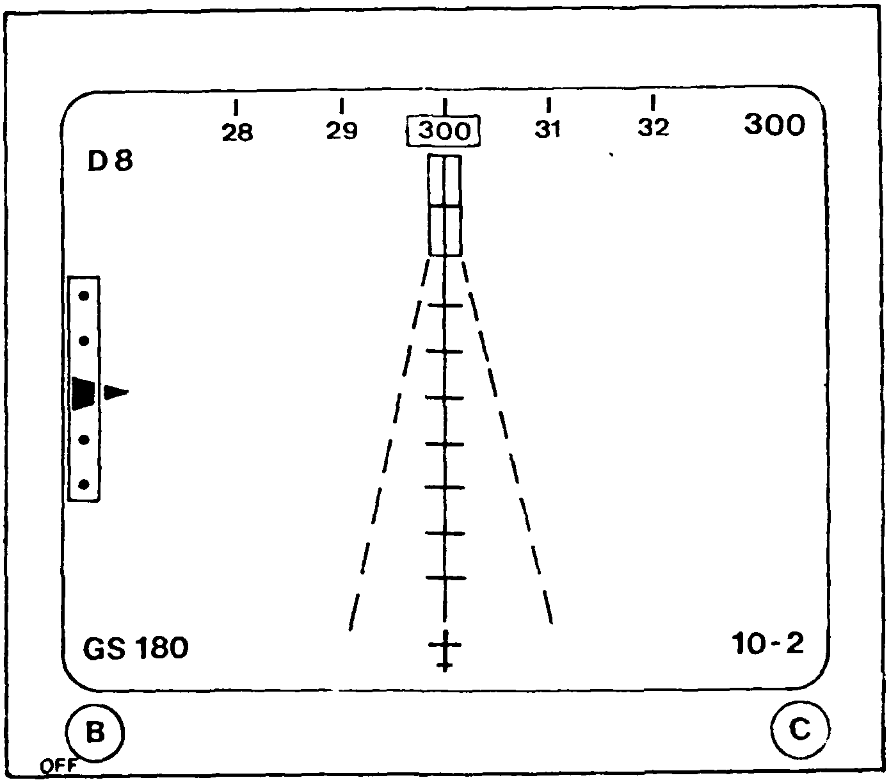


-- ILS Map Format --

Computer Nav Mode/Track-up Presentation

Moderate and Major Updates

(Note: Aircraft position closer to airfield/Range: 40 mi)

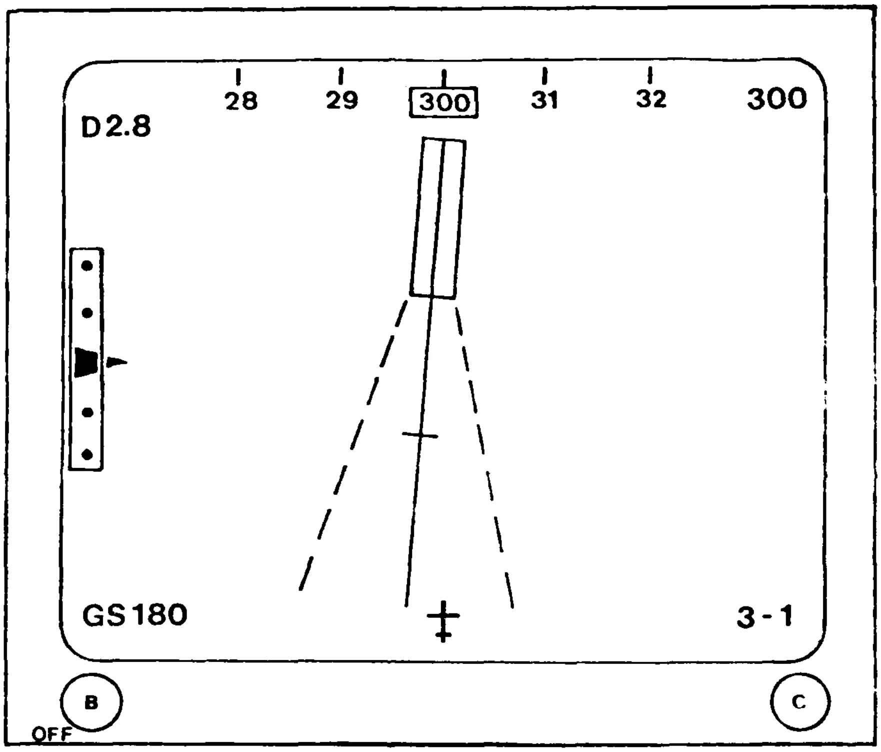


-- ILS Map Format --

Computer Nav Mode/Track-up Presentation

Moderate and Major Updates

(Note: Aircraft position closer to airfield/Range: 10 mi)

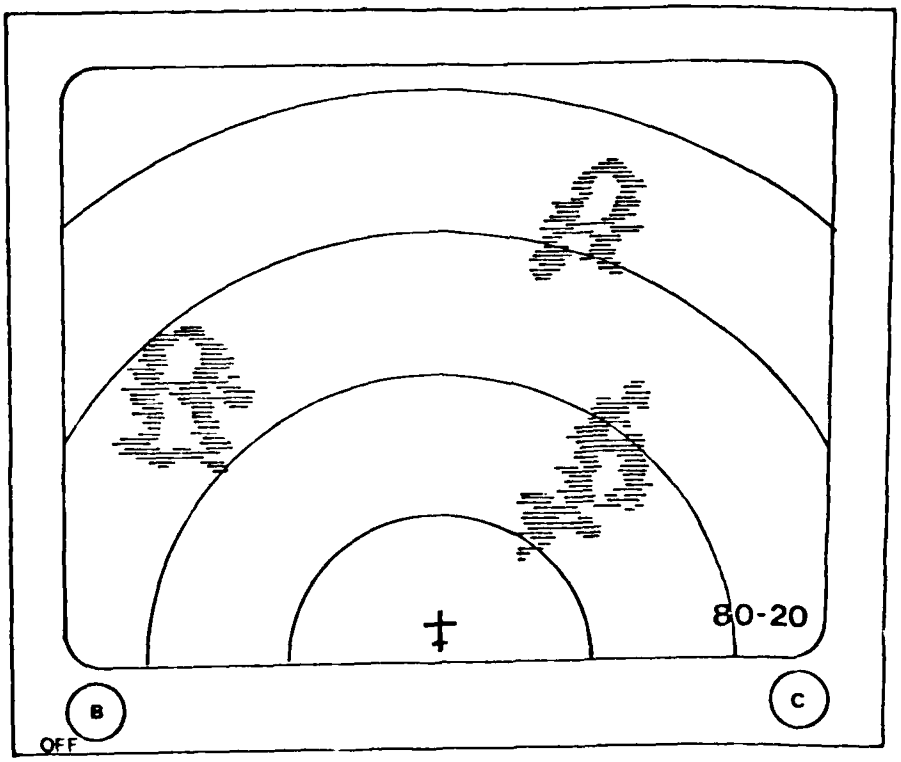


--ILS Map Format --

Computer Nav Mode/Track-up Presentation

Moderate and Major Updates

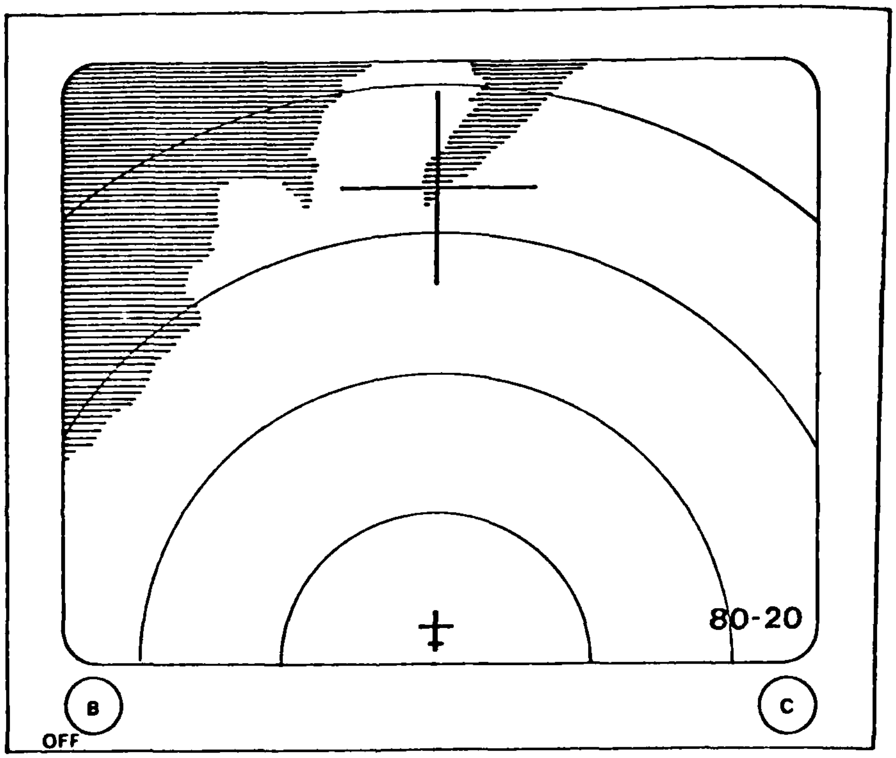
(Note: Aircraft position closer to airfield/Range: 3 mi)



-- Weather Radar Display --

Nav Mode and Format Not Selected

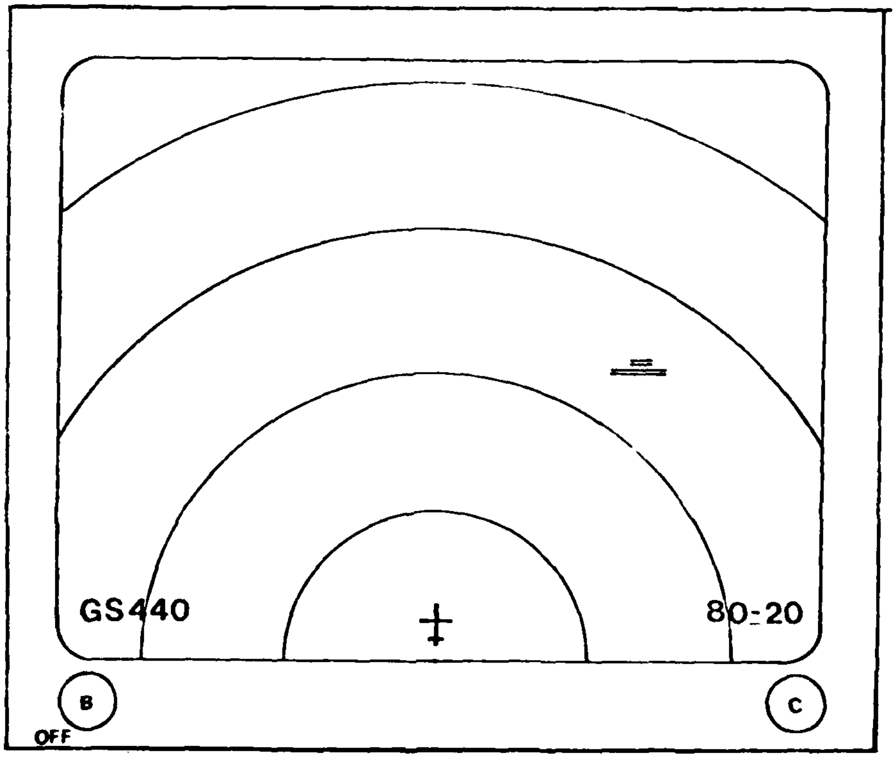
Moderate and Major Updates



-- Ground Mapping Radar Display With Cursor --

Nav Mode and Format Not Selected

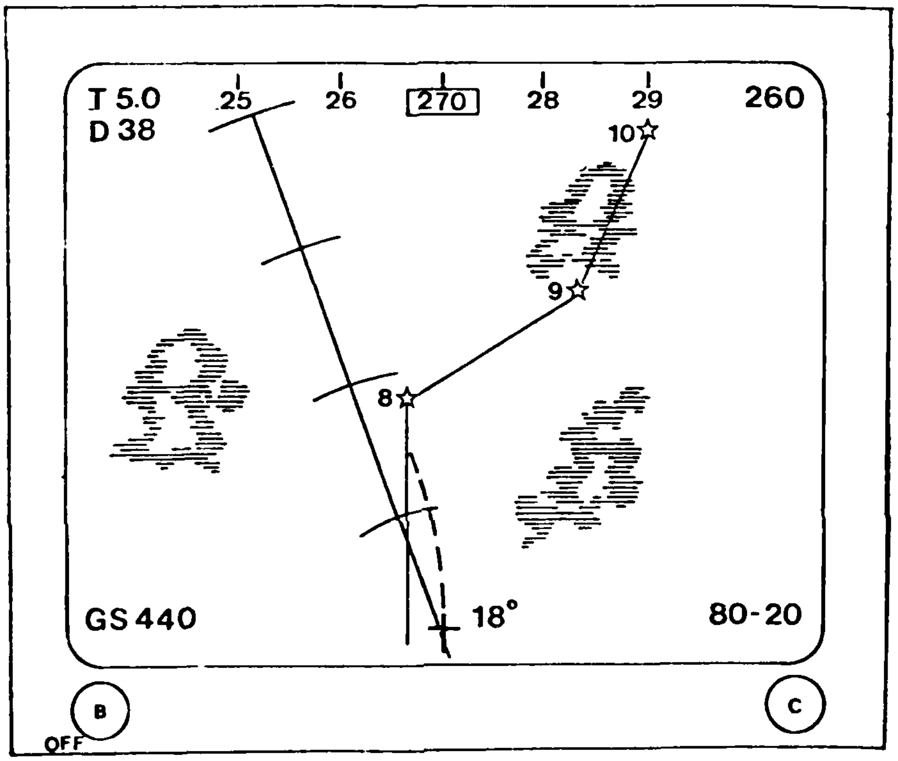
Moderate and Major Updates



-- Aircraft Radar Beacon Display --

Nav Mode and Format Not Selected

Moderate and Major Updates



-- Map Format With Weather Radar Overlay --

Computer Nav Mode/Track-up Presentation

Moderate and Major Updates

(Note: Momentary sweep line for plotting heading deviations)

APPENDIX B

Rating Scale Package Administered to the Pilots and Copilots

Rating Scale Package Administered to the Boom Operators

PILOT/COPILOT RATING SCALE PACKAGE

The purpose of the questionnaires that you are going to be filling out is to determine as accurately as possible your feelings and preferences about the varied crew station configurations to which you will be exposed. Through the questionnaires, we will be able to document your opinion and objectively analyse the results of the experiment. The questionnaires are designed to help you think about each crew station design (both during and after each "flight") so that you can help us better assess each design's good and bad points. We ask that you be aware of each design's shortcomings (as well as their strong points) and be thinking about better ways to configure each design during each "flight".

When completing the questionnaires, make any comments that you see fit anyplace in the questionnaire (there is no need to restrict yourself to the "comments" sections). Please fill out the questionnaires as best you can--we know that at times they may appear too tedious and lengthy but because we are limited in the number of subject crews at our disposal, we must obtain maximum data from you!

DEFINITIONS

During the mockup flights you will be asked to rate the operation of different flying tasks. The tasks you will be rating are communications, navigation, piloting, paperwork, and "other" tasks. Each of these groups of tasks are defined below:

COMMUNICATION - The operation of all communications equipment and communication on that equipment -- tuning, transmitting, receiving, and frequency recognition for all communication radios.

NAVIGATION - The operation of all navigation equipment and navigation on the information provided -- tuning, receiving, waypoint programming, interpreting information on flight instruments, interpreting guidance information, and ground mapping radar.

PILOTING - Aircraft maneuvering, airspeed control, mission control and command, and SKE.

PAPERWORK - Calculating take-off and landing data, CG computation, AFTO Form 781, mission progress forms, fuel log, and other tasks involving "paper and pencil" computations.

"OTHER" TASKS - Aircraft subsystems controls, weather radar, crew coordination/briefings, see and avoid, and checklists.

RATING SCALES

During the mockup flights, you will be asked to rate workload and equipment for quality and capabilities. The three scales to be used are given as follows:

Scale I (Quality Level)

Rating	
10	Excellent (needs no improving)
9	Very Good
8	
7	Good
6	
5	Fair, but useable
4	
3	Poor (Almost not useable)
2	
1	Very Bad
0	Unacceptable - not useable

Scale II (Workload Level)

Rating	
10	Overload
9	Extreme
8	
7	Significant
6	
5	Moderate
4	
3	Low
2	
1	Very low
0	No work

Scale III (Requirements/Capabilities)*

Rating	
10	Would or did enhance mission performance so much as to be absolutely necessary to to perform the mission.
9	Would or did enhance mission performance greatly - extremely useful. Requirement recommended.
8	
7	Would or did noticeably enhance mission performance - quite useful. Requirement partially recommended.
6	
5	Would or did enhance mission performance somewhat - useful, but not required.
4	
3	Wouldn't or didn't really enhance mission performance - only sometimes useful.
2	
1	Wouldn't or didn't enhance mission performance whatsoever - not useful.
0	Couldn't use it even if it was available.

* This scale is a continuum from an "absolute necessity" rating (10) to an "absolutely could not use it" rating (0).

EXAMPLES OF NAV MANAGEMENT "PAGES"

NAV AIDS

AA	AB	AC	AD
AE	AF	AG	AH
AI	AJ	AK	AC
AM	AN	AO	AP
AQ	AR	AS	AT

NAV AID DATA

EDBB	TEMPLEHOF		
PSN	N 523114 E0103412		
CHAN	89		
FREQ	114.20	321	382
	415	DF	GCA
	ILS		

◇ FLT PLAN

FROM	EDAF		0368
280	LL 1	97	4000
037	BD 1 HOLD	102	FL70
062	BD 2	36	"
351	HAM	12	FL190

WAYPOINT DATA

◇ WPT BERRY N531140 E0103220 FFO 307/124

◇ GMT 1410:10

FLT PLAN→ →ETA 1429:45
→TTW 19:35
→DTW 163.9

GS 245

PSN FROM BERRY 179/163.9

PRESENT POSITION

◇ N422810 W1290736

◇ GMT 1219:10

TAS 355	GS 245
WIND 228/106	DRIFT L 10
◇ IDENT	RAD/DIST FROM:
OSCAR	357/128

◇ CENTER OF GRAVITY (CG)

BASIC WT	______
CREW WT	______
FUEL	______
#1 MAIN	______
#2 MAIN	______

FUEL STATUS

LBS X 100

FB+378

2+149	CW+475	3+149
1+138	AB+417	4+138
1R+28	UD+142	4R+28

TOTAL+2047

◇ TOLD

TAKEOFF DATA

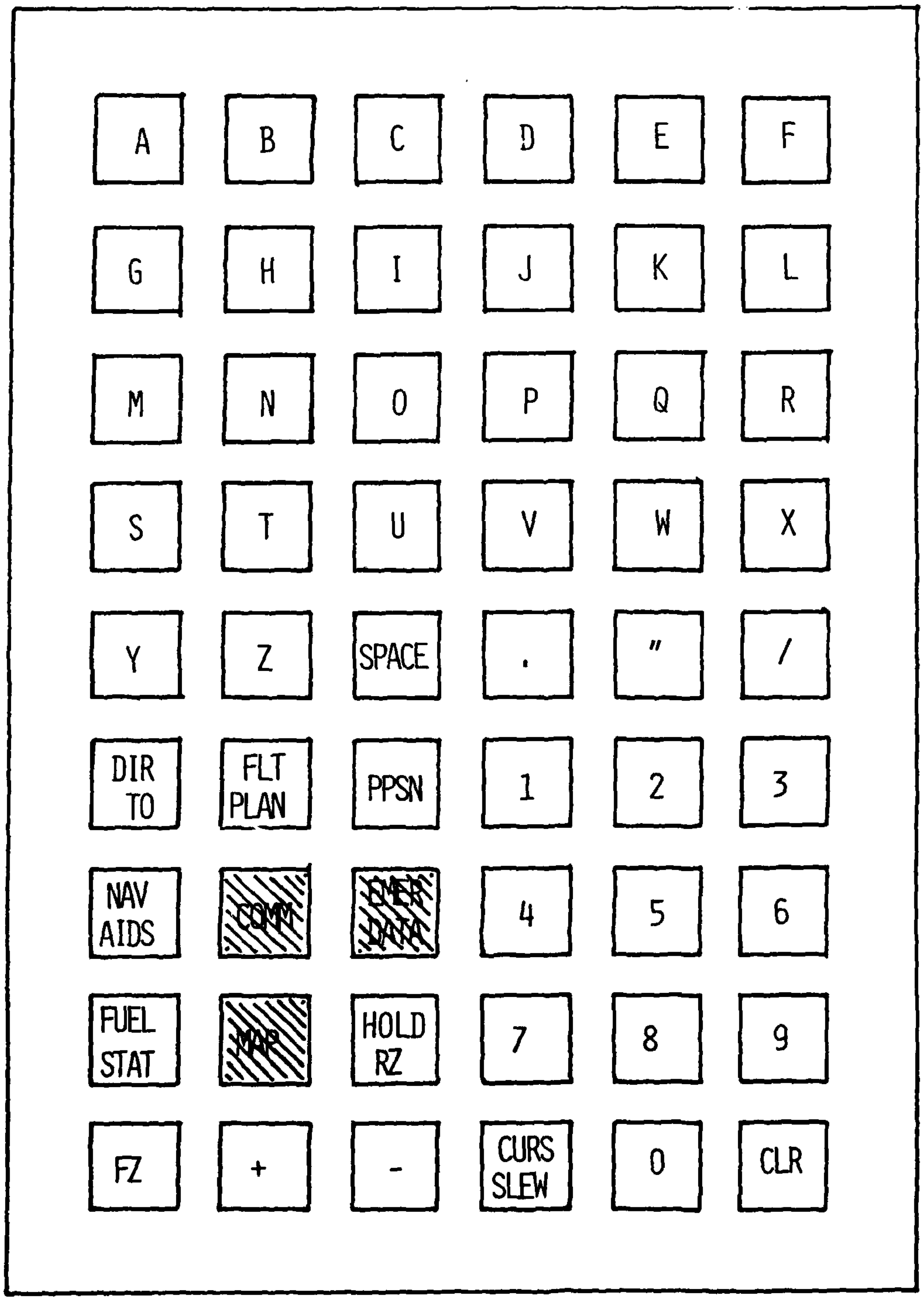
GROSS WT	221300
RWY HDG	140
RWY LGTH	11354
RWY GRADE	0
RWY RCR	21

◇ HOLD/RZ

INB CRS	270
TURNS	R
INB LEG-MILES	5

PUSH TO INSERT

NAV MANAGEMENT CDU KEYBOARD



Represents functions that either were not operable or were changed completely

BOOM OPERATOR RATING SCALE PACKAGE

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NAVIGATION - The operation of all navigation equipment and navigation on the information provided -- tuning, receiving, waypoint programming, interpreting information on flight instruments, interpreting guidance information, and ground mapping radar.

AERIAL REFUELING - Includes refueling receivers, the operation of all refueling related equipment, and the performance of specified refueling computations.

PAPERWORK - Calculating take-off and landing data, CG computation, AFTO Form 781, mission progress forms, fuel log, and other tasks involving "paper and pencil" computations.

"OTHER" TASKS - Aircraft subsystems controls weather radar, crew coordination/briefings, see and avoid, and checklists.

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Rating	
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9	Extreme
8	
7	Significant
6	
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4	
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2	
1	Very low
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Scale III (Requirements/Capabilities)*

Rating	
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4	
3	Wouldn't or didn't really enhance mission performance - only sometimes useful.
2	
1	Wouldn't or didn't enhance mission performance whatsoever - not useful.
0	Couldn't use it even if it was available.

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APPENDIX C

Horizontal Situation Display (HSD) Switchology, Formats

and Associated Controls

HORIZONTAL SITUATION DISPLAY (HSD) SWITCHOLOGY, FORMATS AND ASSOCIATED CONTROLS

An HSD is located on the pilot's and copilot's instrument panels, immediately below the ADI. The device replaces the standard HSI and presents plan-view navigation information, radar information or a mixture of both. The information on the display is controlled through a switching matrix (Figure 1) located adjacent to the display. Switching functions for the two displays are independent of each other, permitting individual display selection by each pilot. The displays are used in conjunction with the flight director system, navigation computer and integrated navigation control-display unit (CDU). The switching matrix provides switches for controlling Navigation Mode Selection, HSD Format Selection and Function Selection.

1. The operation of each Nav Mode Selection switch is as follows:

a. <u>CMPTR (Computer)</u> - Depressing this legend switch causes computer generated navigation information to be made available to the HSD for display through the HSD Format Selectors. Computer generated navigation information is navigation data derived from the INS, Doppler, available radio aids to

HSD MODE SELECTOR SWITCHES

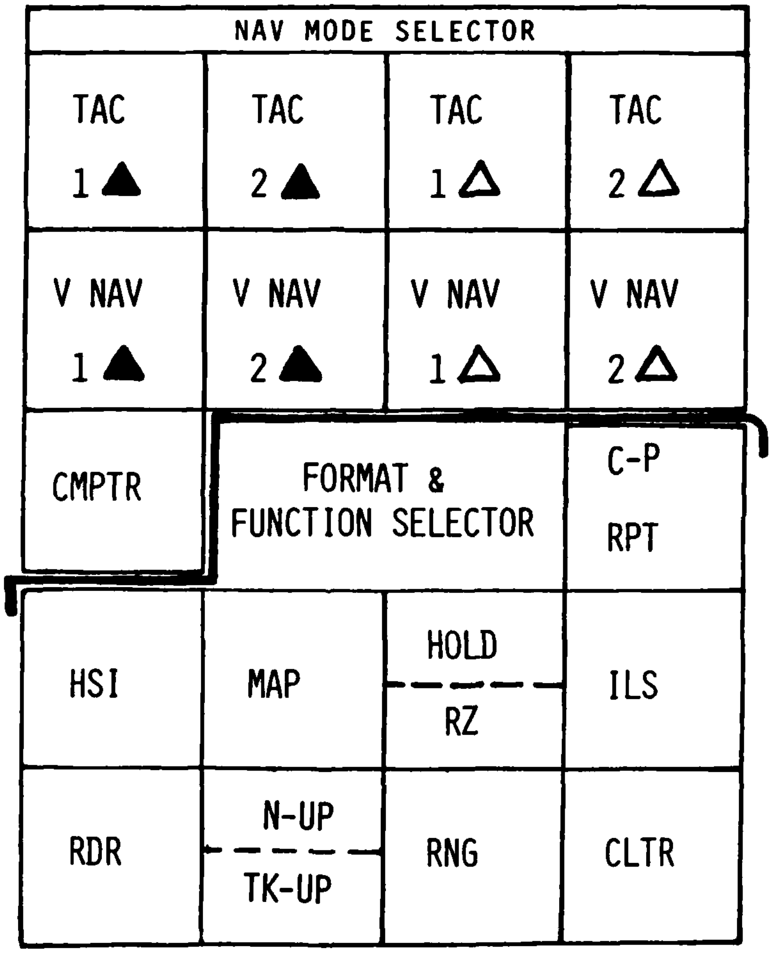


FIGURE 1

navigation, CADC and AHRS. Under normal operating conditions, the CMPTR mode will be the most reliable estimate of the aircraft's navigation situation. This mode is not used for TACAN, VOR or ILS approaches, (except for computer generated map ILS approaches which are described in the section on ILS).

b. ▲ SWITCHES (solid symbol indicates both bearing and CDI information available). With CMPTR NAV Mode selected these switches are disengaged and the ♠ bearing pointer and CDI on an HSI format will display course to the next flight plan way-point. When one of these four ▲ switches are selected, course guidance information, in conjunction with a selected COURSE, will be displayed on the HSD. These switches are mutually exclusive, i.e., only one can be activated at any one time. They are also mutually exclusive with the CMPTR switch. The switches illuminate when activated. When a switch is pressed, it illuminates and the previously activated switch is deactivated. When an illuminated switch is pressed, nothing happens (no "off" function). If a ▲ switch is selected and the ground signal is insufficient, ♠ bearing pointer will rotate CCW and the CDI will swing from side to side. If a ▲ switch is selected and R/T unit is "off", ♠ bearing pointer disappears and CDI will stow to the side of the case.

(1) TACAN #1▲, TACAN #2▲ - Depressing either one of these switches automatically changes the HSD to the HSI format and permits TACAN, CDI guidance information, in conjunction with a selected COURSE, to be displayed on the HSD. In addition, bearing

to the selected NAV aid is displayed on the ♠ bearing pointer and the distance from the aircraft to the station is displayed.

(2) VHF NAV #1▲, VHF NAV #2▲ - Depressing either one of these switches automatically displays the HSI format and permits CDI guidance information, in conjunction with a selected course, as well as bearing information (on the ♠ bearing pointer), on the HSD, if a VOR frequency is tuned in the respective RT unit, or localizer course deviation, if an ILS frequency is tuned in the respective RT unit. If an ILS frequency is tuned for the selected VHF NAV #1 or #2 ▲ switch, the bearing pointer symbol (♠) will disappear from the HSD.

Note: CDI guidance information relative to a ground-based nav aid can only be displayed if the Nav aid is selected on one of the ▲ bearing selector switches.

c. △ SWITCHES - open symbol indicates only bearing information available (no CDI). These selector switches permit bearing information to be displayed on the ♤ bearing pointer on the HSD, when the display is in the HSI format. These switches are mutually exclusive. VHF NAV △ switches can be used in conjunction with the CMPTR NAV Mode and HSI Format to provide VOR bearing information. TACAN △ selectors are not available when in the CMPTR NAV mode because TACANS are being auto tuned. However, TACAN information is displayed on ♤ pointer if no △ switches are depressed and "CMTR" is selected and has auto tuned a TACAN R/T unit; △ TACAN switch will not light up; TACAN ♤ ID will be on PPSN page; ♤ will be auto tuned to strongest TACAN signal.

(1) TACAN #1 △, TACAN #2△ - Depressing either one of these two switches places bearing information to the repective TACAN station on the ⇧ bearing pointer and the distance from the aircraft to the station is displayed. These switches are only active when the HSI Format has been selected and when CMPTR is not selected because of the TACAN autotuning feature.

(2) VHF NAV #1 △, VHF NAV #2△ - Depressing either one of these two switches displays bearing information to the VOR tuned in the selected RT unit on the ⇧ bearing pointer.

Note: Depressing a VHF NAV ⇧ bearing pointer switch in which an ILS is tuned will cause the displayed ⇧ pointer to disappear from the HSD since only the ▲ bearing pointer switches can be used in conjunction with an ILS. The light in the △ switch will blink. If an ILS frequency is tuned after a VHF NAV △ has been depressed and illuminated, the effect is the same.

Note: The NAV Mode Selector Switches replace the TACAN Select Switch currently found in the KC-135. Thus, in addition to the effect they have on the HSD, they interface with the Flight Director. If CMPTR is selected (Flight Director Mode Selector Switch in NAV/LOC), the Command Bars present command information to fly the flight plan course as defined through the Navigation Management Control-Display Unit. With any of the ▲ BEARING select switches depressed, the flight director command bars will provide information

to fly the selected course to the Nav aid, if a TACAN or VOR facility is tuned, or the localizer and glide slope, if an ILS is tuned and the Flight Director Mode Selector is in APP MAN or APP AUTO. The Δ BEARING select switches do not effect the operation of the Flight Director.

2. The description of the format and function selector switches is divided into two sections for clarity. The operation of the HSD Format Selection switches is as follows:

a. <u>HSI (Horizontal Situation Indicator)</u> - Selection of this legend switch causes the HSI format to be displayed on the HSD and the HSI switch light to illuminate. HSI may be selected for any of the NAV Modes with the information being displayed a function of the NAV Mode selected.

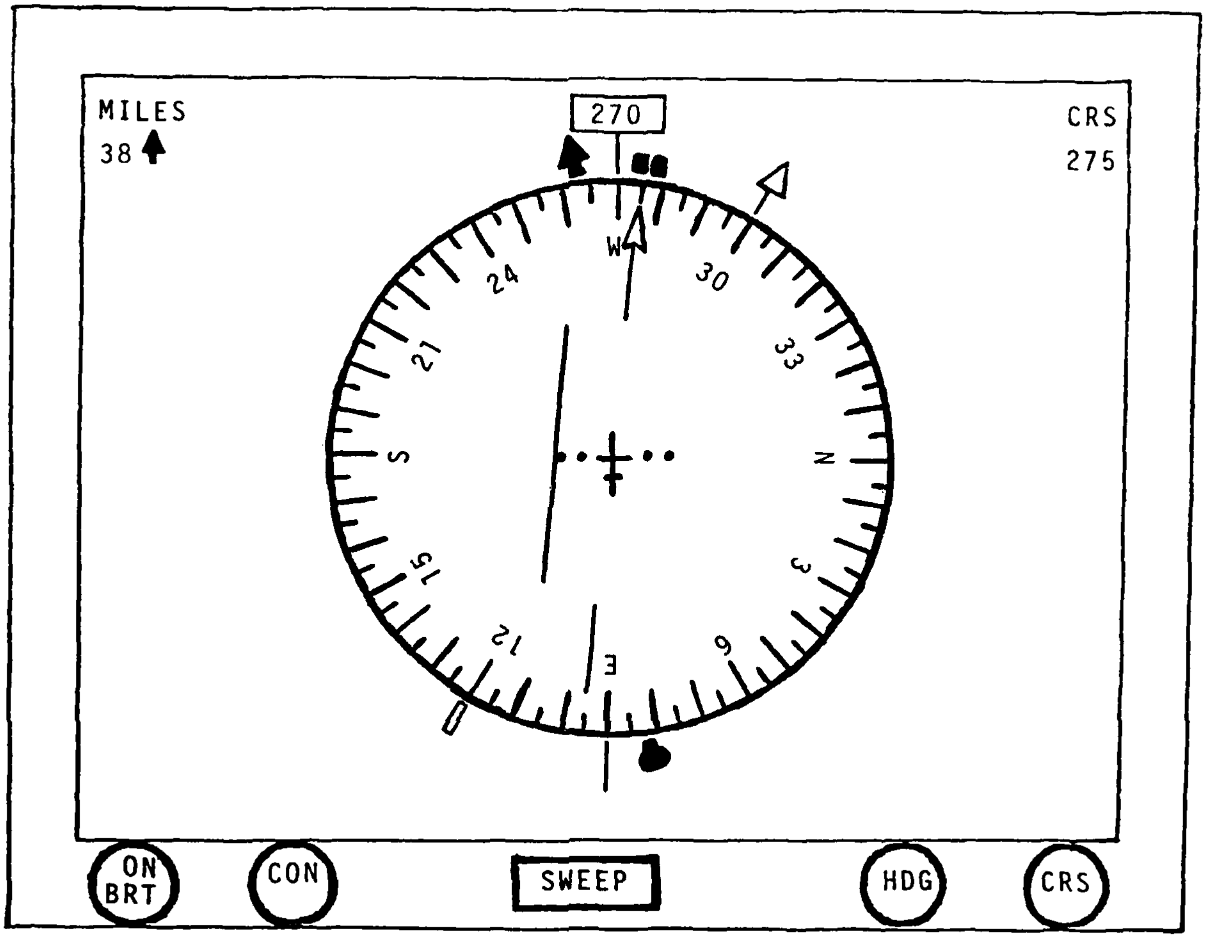
(1) If CMPTR is selected, the HSI format (⬆ and CDI) provides COURSE information relative to the computer generated flight plan course. The CRS SET (Course Set) knob is declutched and course deviation information is relative to the flight plan course. Without a flight plan, the ⬆ will rotate CCW. Bearing information is displayed as a function of the selected V NAV BEARING Δ switch (TAC Δ switches are inactive). If no V NAV is selected, TACAN info may be displayed on ⇧ if TACAN is auto tuned.

(2) If a ▲ (BEARING and CDI) switch is selected, the HSI format presents digital course, course deviation and bearing information relative to the Nav aid tuned in the respective RT unit, with desired course selected through the CRS SET knob. Without an adequate ground signal (R/T unit on), ♠ will rotate CCW. Selected ▲ R/T unit off, ♠ and CDI disappears.

(3) If a △ (BEARING ONLY, NO CDI) switch is selected, the HSI presents bearing information relative to the nav aid station, if a TACAN or VOR frequency is tuned in the respective RT unit. If an ILS frequency is tuned in the selected RT unit, the ♤ BEARING pointer will disappear and the △ switch will blink.

Figures 2, 3, 4 and 5 depict some of the possible HSI variations which may be displayed on the HSD. The switch selections necessary to display those specific variations are shaded.

HSI FORMAT - CMPTR NAV MODE



NAV MODE SELECTOR			
TAC 1 ▲	TAC 2 ▲	TAC 1 △	TAC 2 △
V NAV 1 ▲	V NAV 2 ▲	V NAV 1 △	V NAV 2 △
CMPTR	FORMAT & FUNCTION SELECTOR		C-P RPT
HSI	MAP	HOLD / RZ	ILS
RDR	N-UP / TK-UP	RNG	CLTR

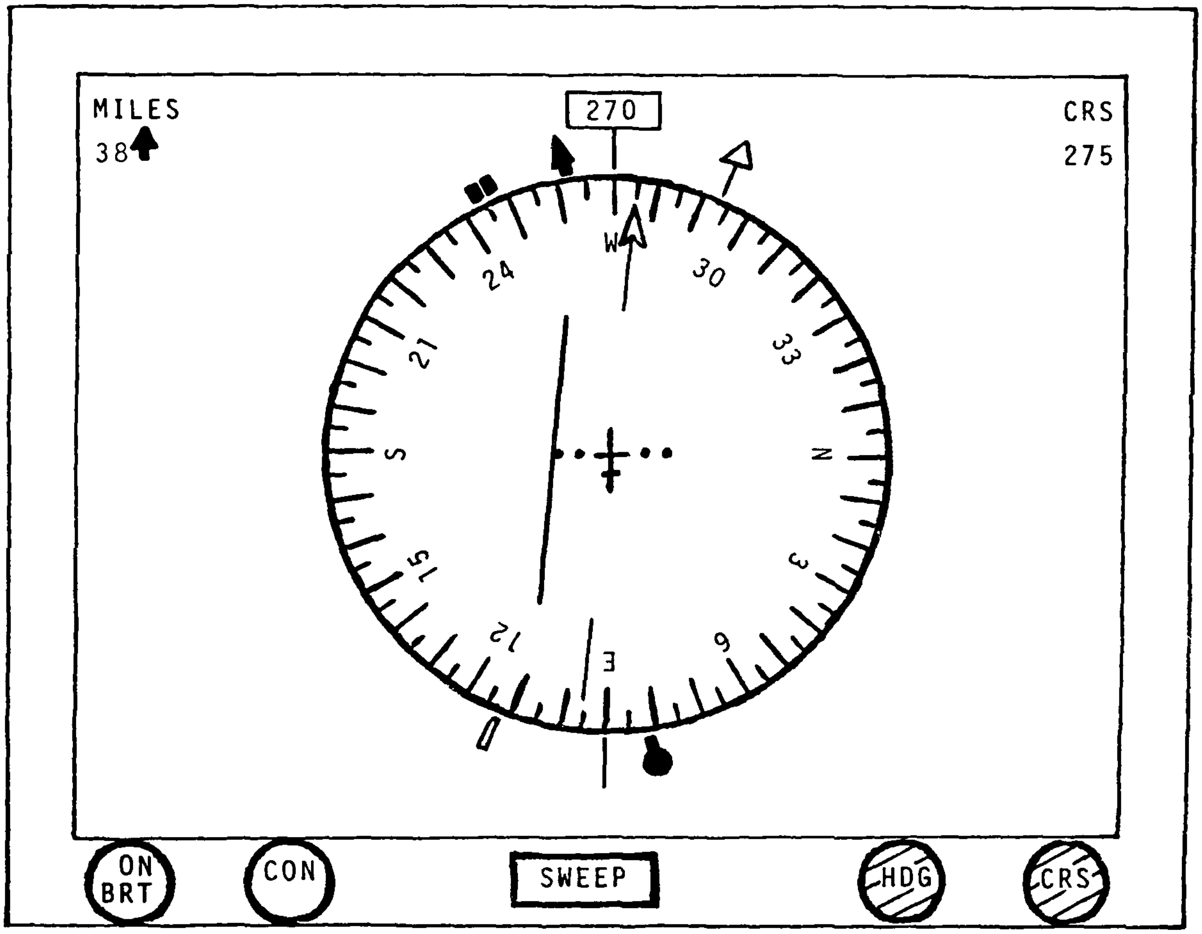
HSD MODE SELECTOR SWITCHES

NOTE:

- ▲ BRG and DIST to waypoint in nav management system.
- △ only BRG information displayed to VOR station (No DME).
- TACAN 1 and TACAN 2 information will be displayed <u>only</u> on PPSN page of nav management system, since they are always auto tuned when in the CMPTR nav mode. When CMPTR is selected, TACAN information displayed on the HSI △ bearing pointer will be from the strongest nav aid signal received.

Figure 2

HSI FORMAT - TAC NAV MODE



NAV MODE SELECTOR			
TAC 1▲	TAC 2▲	TAC 1△	TAC 2△
V NAV 1▲	V NAV 2▲	V NAV 1△	V NAV 2△
CMPTR	FORMAT & FUNCTION SELECTOR		C-P RPT
HSI	MAP	HOLD / RZ	ILS
RDR	N-UP / TK-UP	RNG	CLTR

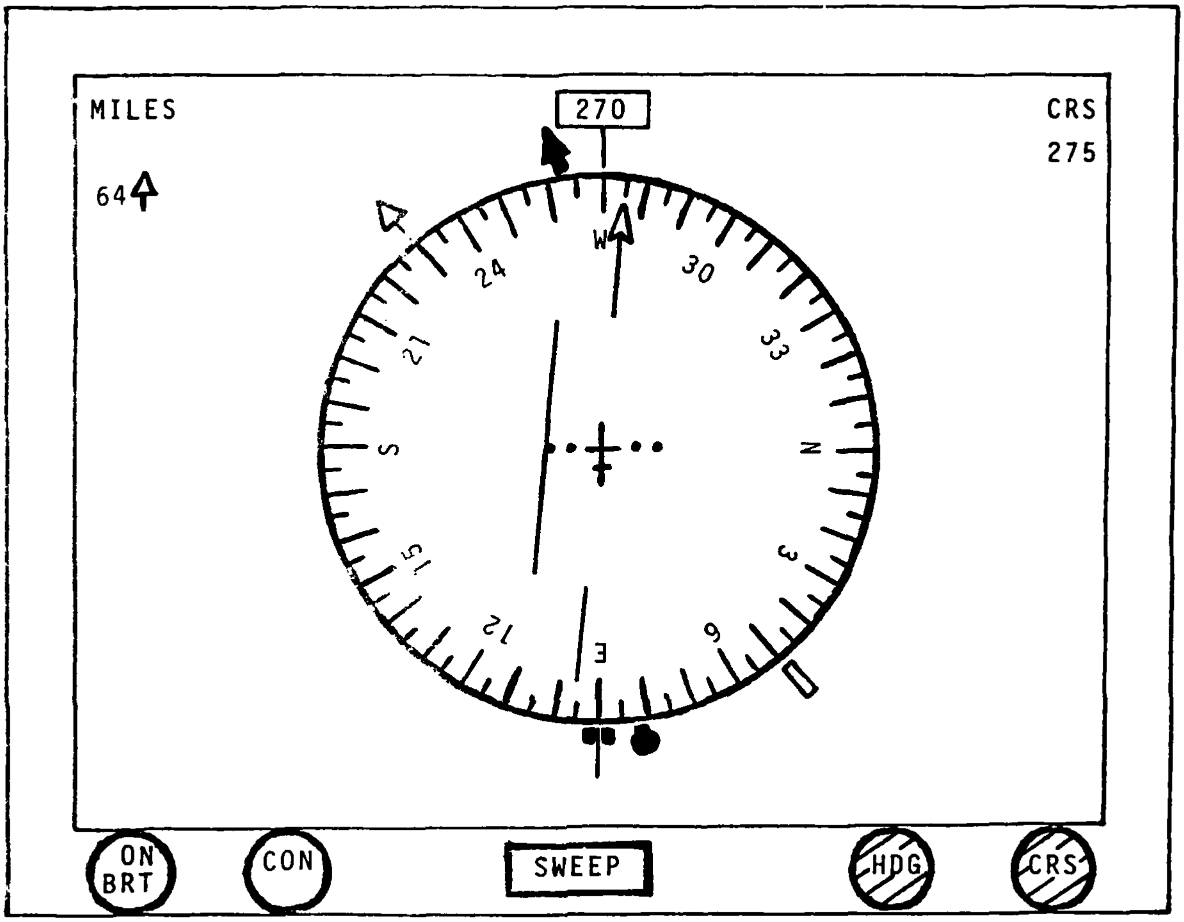
HSD MODE SELECTOR SWITCHES

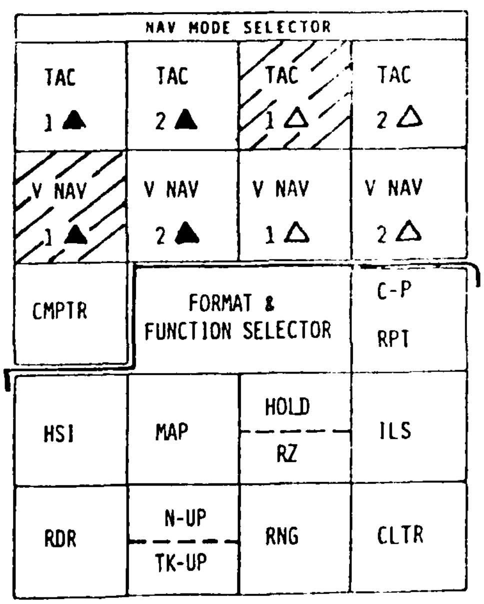
NOTE:

- HSI format automatically displayed.
- ▲ BRG and DIST to manually tuned TACAN station.
- △ BRG to VOR station (No DME).
- HSI switch light illuminates automatically.

Figure 3

HSI FORMAT - VOR NAV MODE





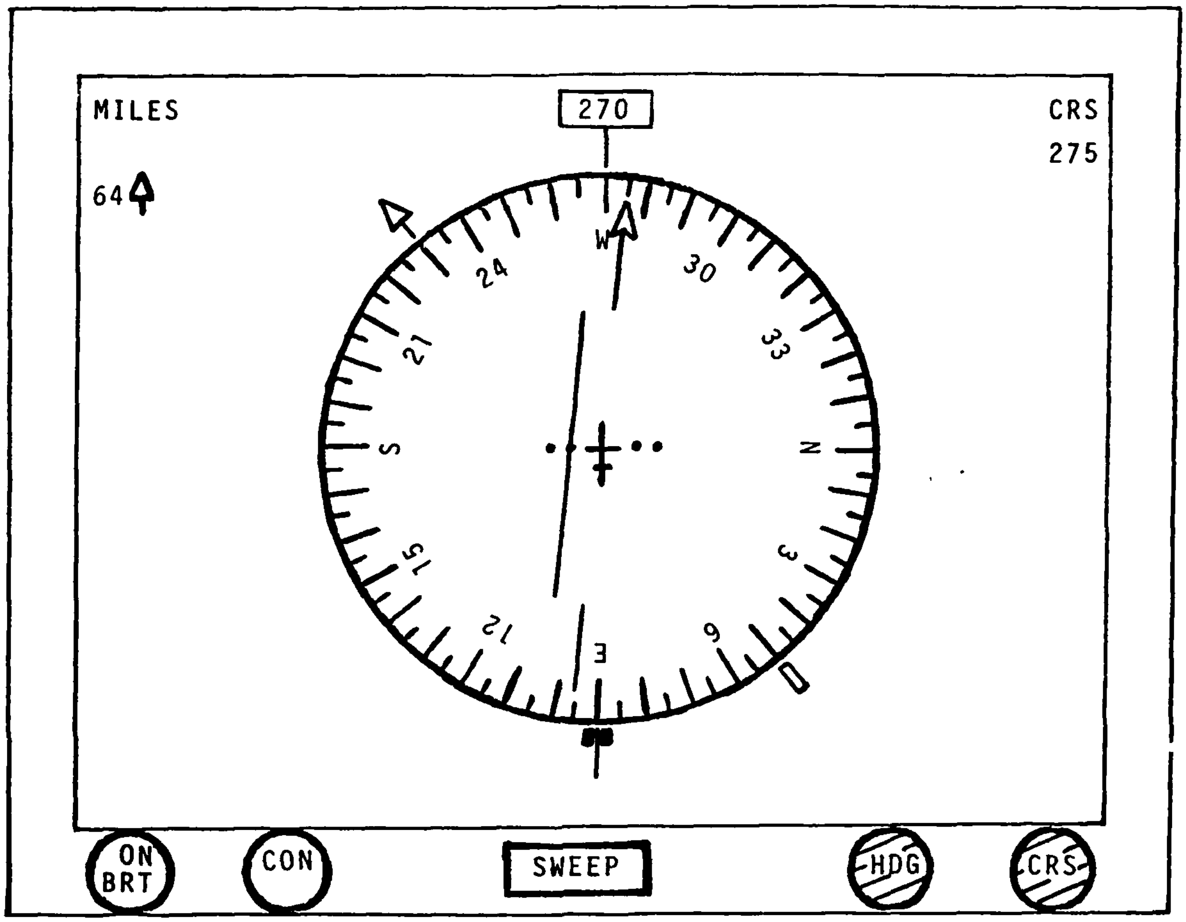
HSD MODE SELECTOR SWITCHES

NOTE:

- HSI format automatically displayed.
- ▲ BRG to VOR station (No DME).
- △ BRG and Dist to manually tuned TACAN.
- HSI switch light illuminates automatically.

Figure 4

HSI FORMAT - ILS NAV MODE



NAV MODE SELECTOR			
TAC 1▲	TAC 2▲	TAC 1△	TAC 2△
V NAV 1▲	V NAV 2▲	V NAV 1△	V NAV 2△
CMPTR	FORMAT & FUNCTION SELECTOR		C-P RPT
HSI	MAP	HOLD / RZ	ILS
RDR	N-UP / TK-UP	RNG	CLTR

HSD MODE SELECTOR SWITCHES

NOTE:

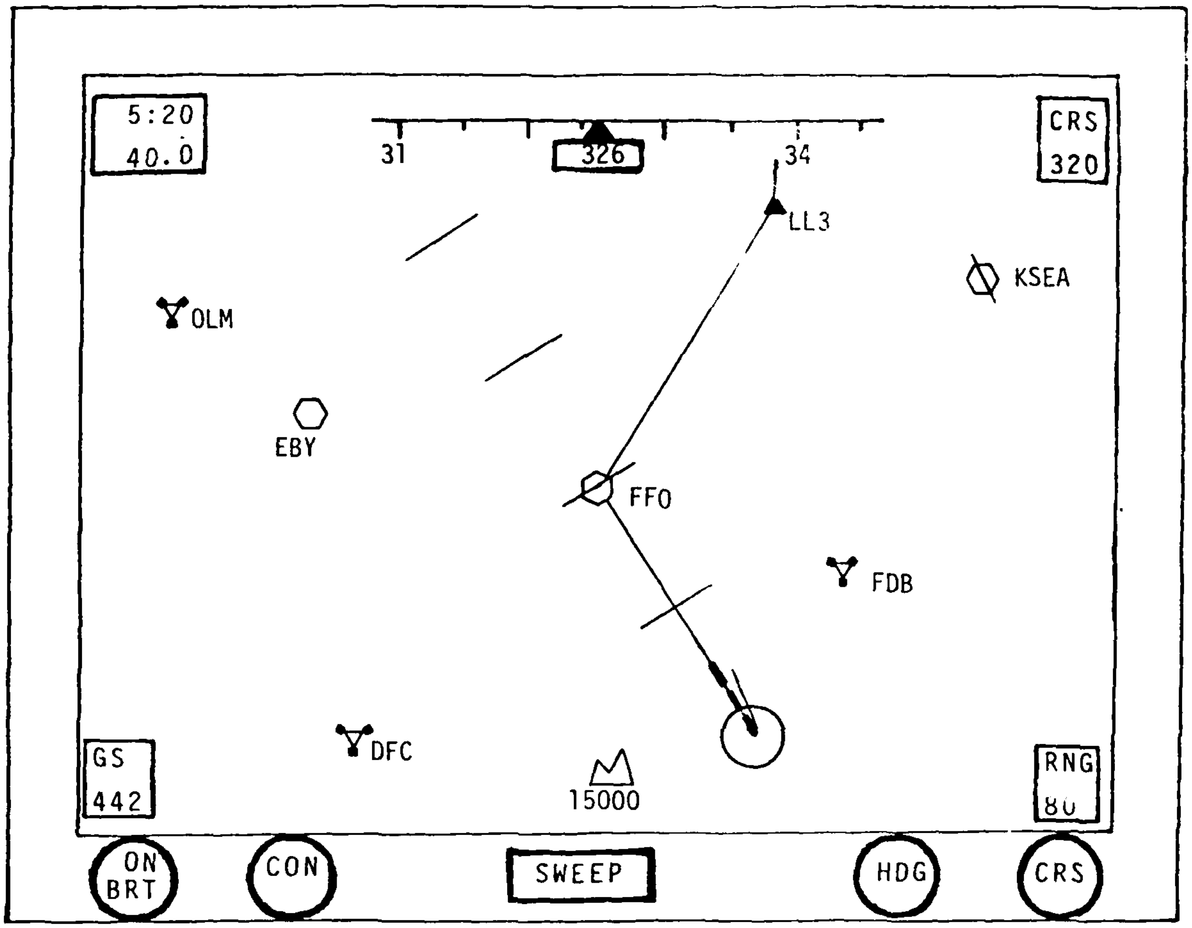
- HSI format automatically displayed.
- VHF NAV 1▲ tuned to ILS frequency so ▲ is not visible.
- △ BRG and Dist to manually tuned TACAN station.
- HSI switch light illuminates automatically.

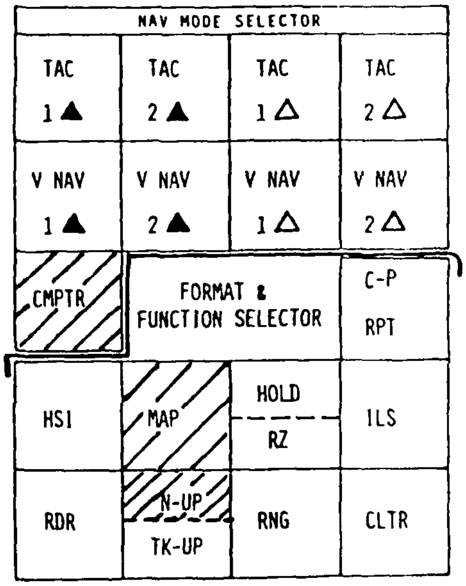
Figure 5

b. MAP - Selection of this mode causes the MAP format to be displayed on the HSD. The MAP format is only selectable if the CMPTR Nav Mode is selected. If any Nav Mode other than the CMPTR Nav Mode is selected, the MAP select switch will not activate, and the display will not change.

Figures 6, 7, 8 and 9 depict some of the possible MAP format variations which may be displayed on the HSD. The switch selections necessary to display those specific variations are shaded.

HSD MAP FORMAT - NORTH UP (CLUTTERED)





HSD MODE SELECTOR SWITCHES

NOTE:

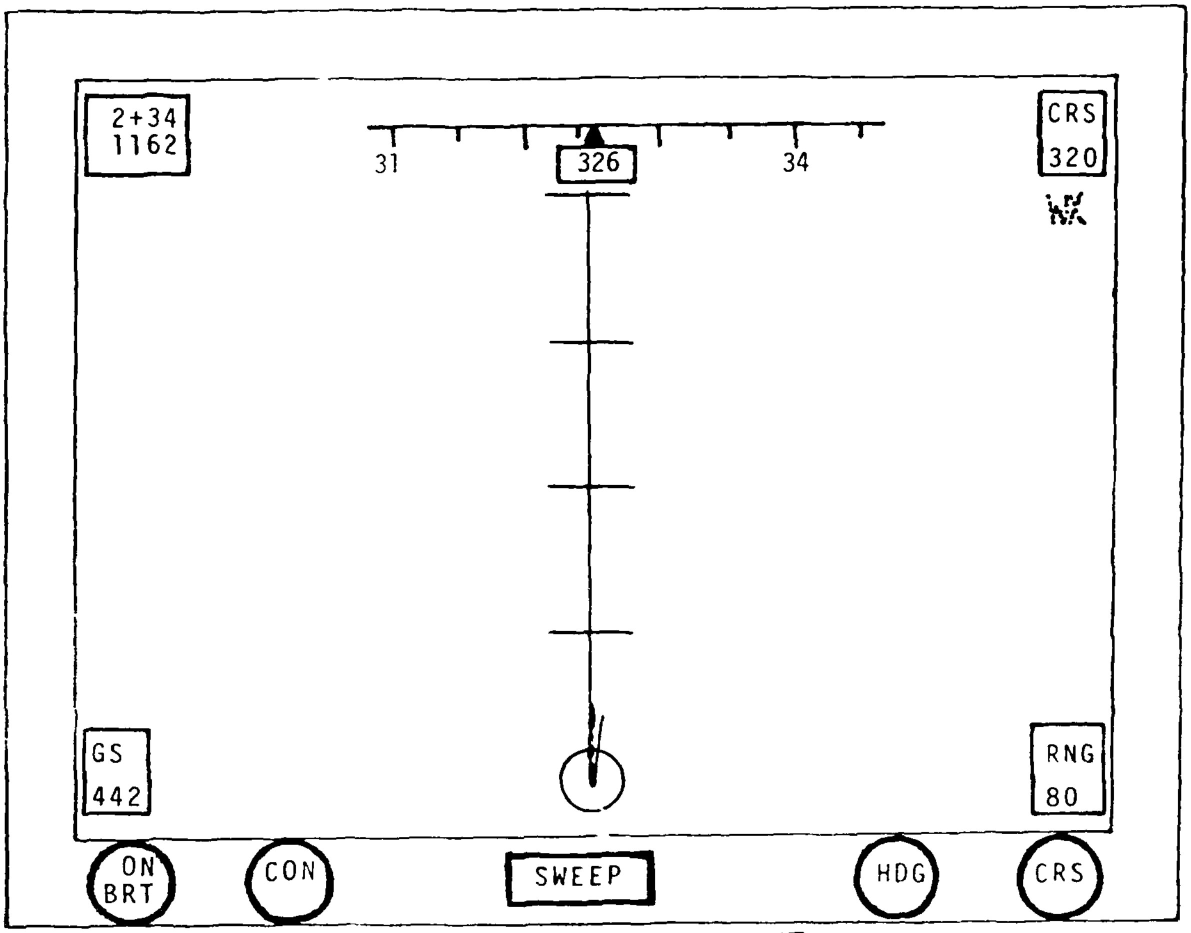
- Range marks always indicate the present (instantaneous) track of the aircraft over the Earth's surface.
- Predictor lines show that the desired course (320°) is being maintained.

NOTE:

- Clutter refers to amount of symbology displayed.
- Box in upper left hand corner indicates time in minutes and seconds and distance in miles and tenths of miles.
- Aircraft symbol shows a right drift correction of 6° (326° vs 320°).

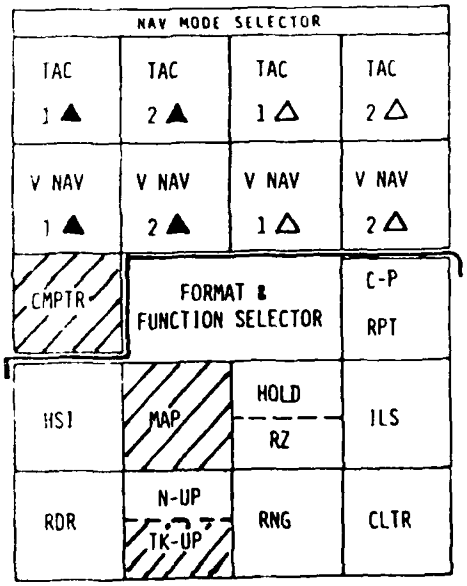
Figure 6

HSD MAP FORMAT - TRACK UP (UNCLUTTERED)



NOTE:

- Aircraft symbol shows a right drift correction of 6° (326° vs 320°).
- Aircraft is on course with proper drift correction.



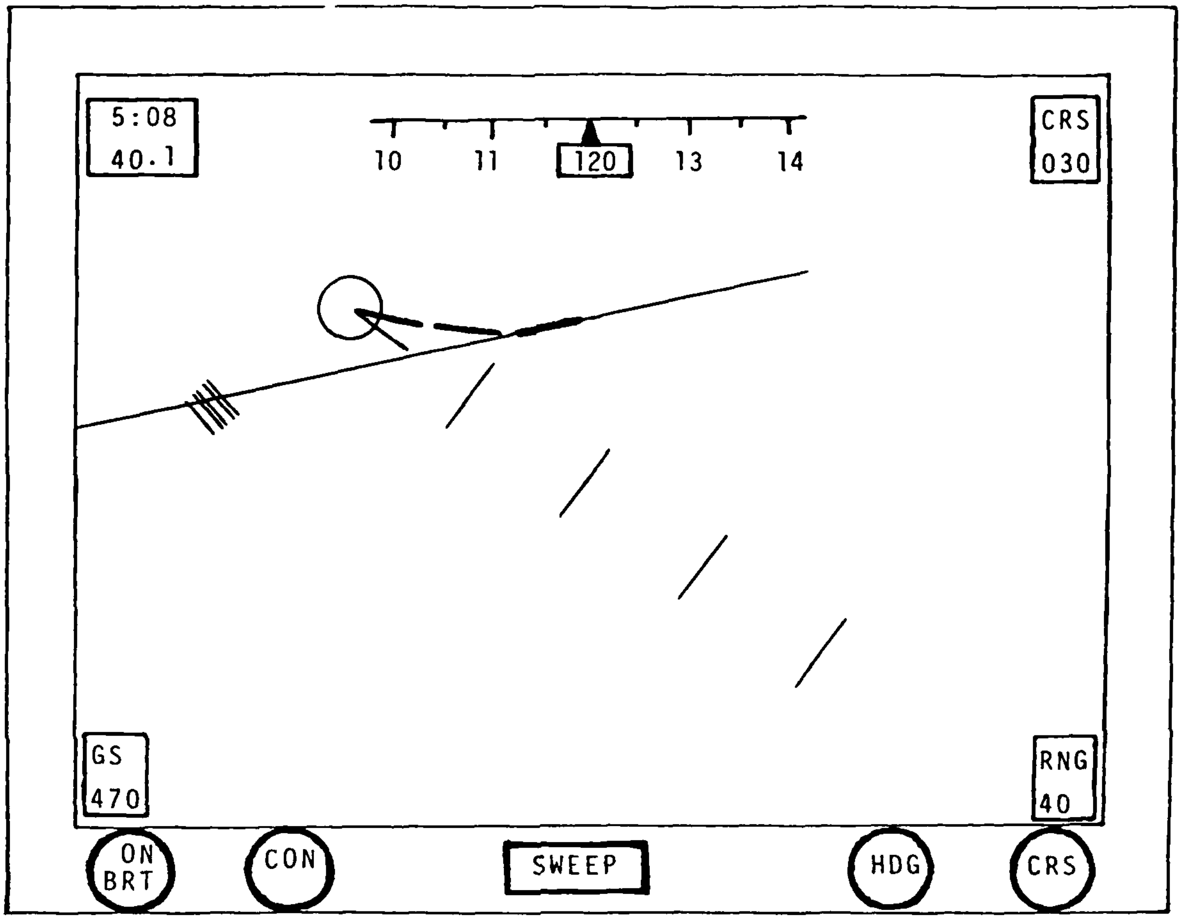
HSD MODE SELECTOR SWITCHES

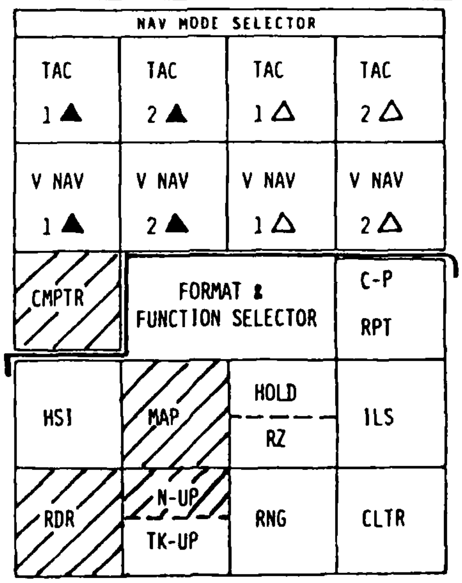
NOTE:

- Radar is ON and in WX or WX CTR mode. Flashing "WX" symbol alerts pilot to display weather radar because it is painting a return.
- Box in upper left hand corner indicates time in hours and minutes when time is more than 60 minutes (: replaced by +), and distance is more than 999 (decimal deleted).

Figure 7

HSD MAP FORMAT





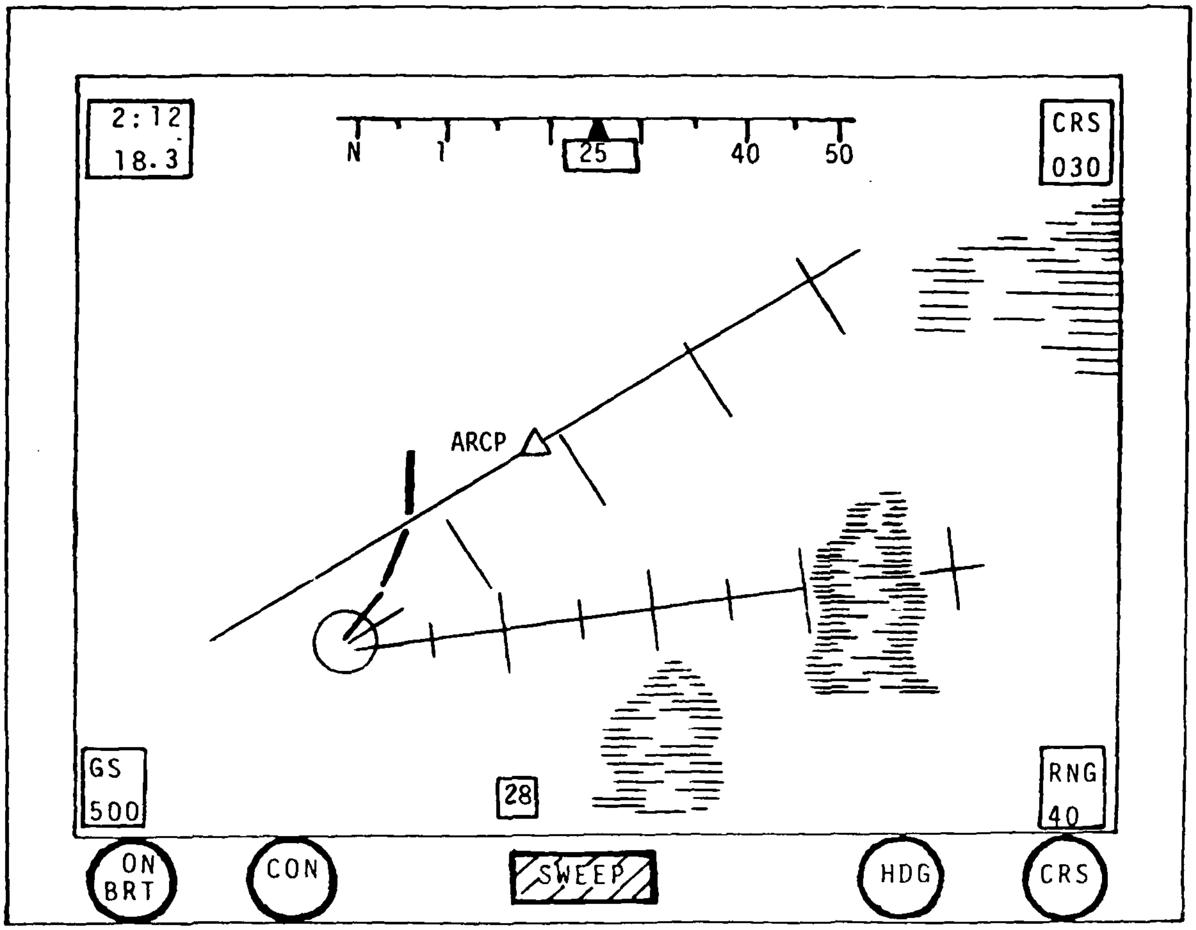
HSD MODE SELECTOR SWITCHES

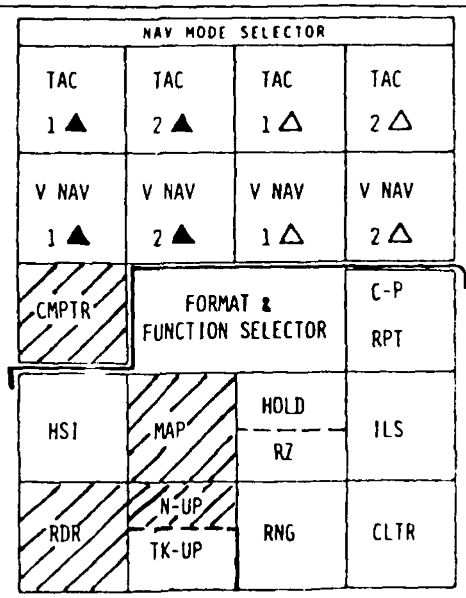
NOTE:

- Radar is in Beacon mode.
- Predictive vector lines indicate aircraft's predicted location at the end of 30, 60, and 90 seconds respectively. Aircraft is in a left turn and will intercept desired course (030°) in 60 seconds.

Figure 8

HSD MAP FORMAT W/RADAR WX





HSD MODE SELECTOR SWITCHES

NOTE:

- Aircraft is off course to the right, in a left turn, and will intercept desired course in 60 seconds.

NOTE:

- Sweep line is displayed 28° right of aircraft longitudinal centerline.
- Radar is in WX or WX CTR mode.

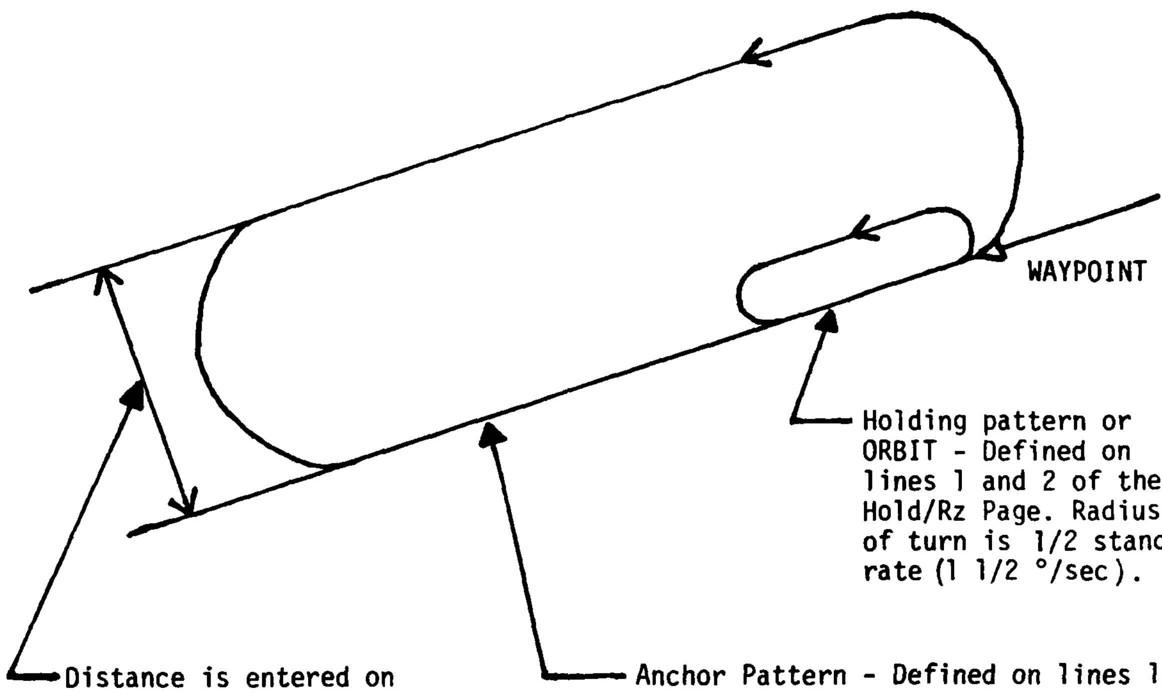
Figure 9

c. HOLD/RZ (HOLD/RENDEZVOUS) - Selection of this HSD mode causes either the HOLD format or the RENDEZVOUS format to be displayed. The parameters presented on these formats are defined for the computer through the Navigation Management Control-Display Unit. The HOLD/RZ switch permits sequential selection of either the HOLD or the RZ format display with successive pushes of the switch. As with the MAP format, HOLD/RZ may only be selected if the CMPTR Nav Mode has been selected. Even if pressed, the switch will remain inactive in an incompatible Nav mode. When HOLD or RZ is selected, the display automatically goes to a North-Up presentation. The display remains in North-Up even after a different format is selected until the N/TK Up switch is cycled. When the RZ format is selected, the flight director is deactivated, requiring the pilot to navigate without commanded information. The flight director reactivates automatically whenever a new format other than RZ is selected.

Figure 10 depicts a Holding Pattern, Orbit and Anchor Pattern.

Figure 11, 12, 13 and 14 depict some of the possible holding pattern, orbit or anchor pattern format variations which may be displayed on the HSD. The sequence shows an aircraft approaching and entering a pattern.

HOLDING, ORBIT, ANCHOR PATTERN

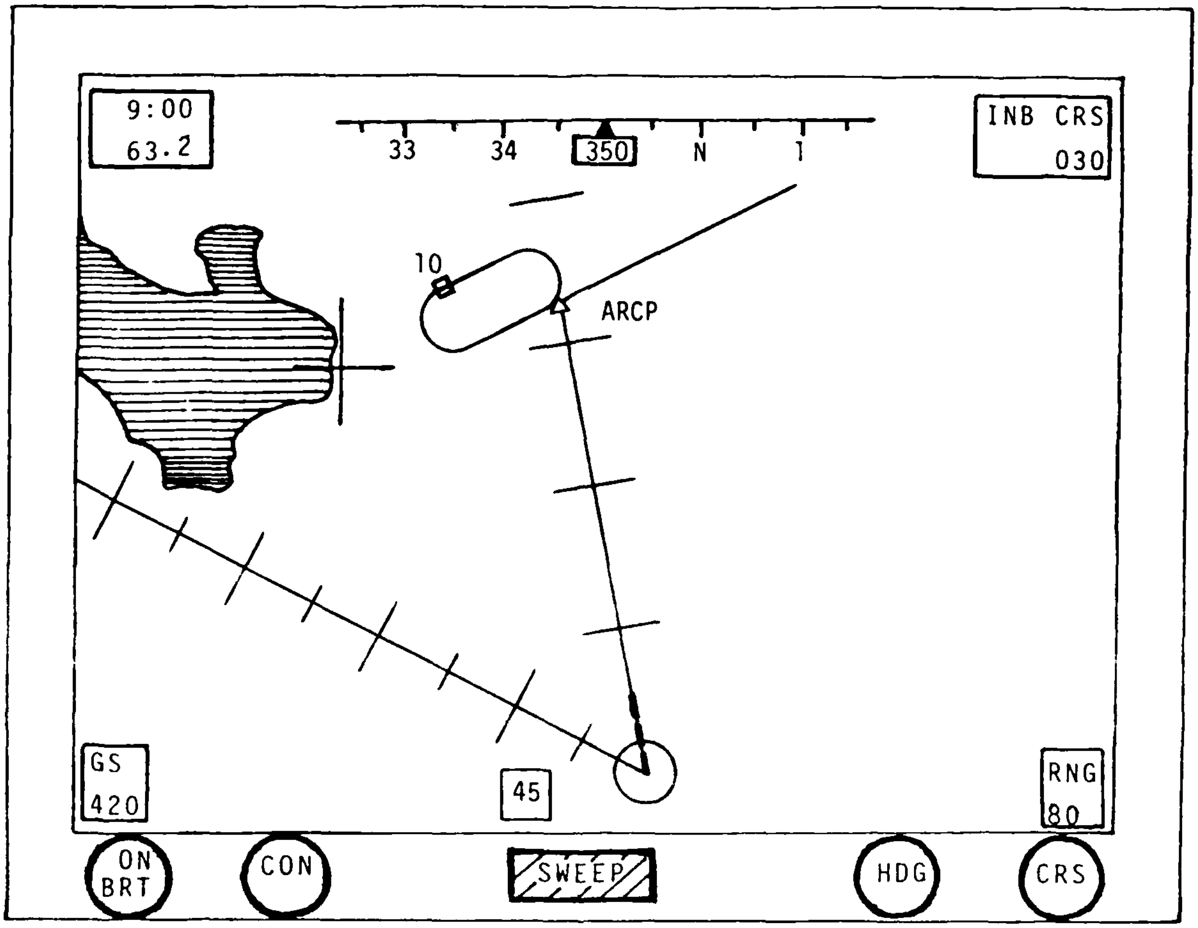


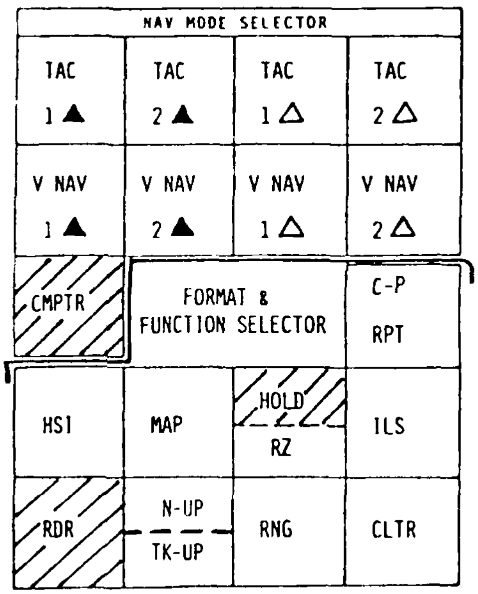
NOTE:

- This diagram is furnished to graphically depict the definition of terms and is not a format that will be displayed.

Figure 10

HOLD FORMAT





HSD MODE SELECTOR SWITCHES

NAV MGT HOLD/RZ PAGE PROGRAMMED AS:

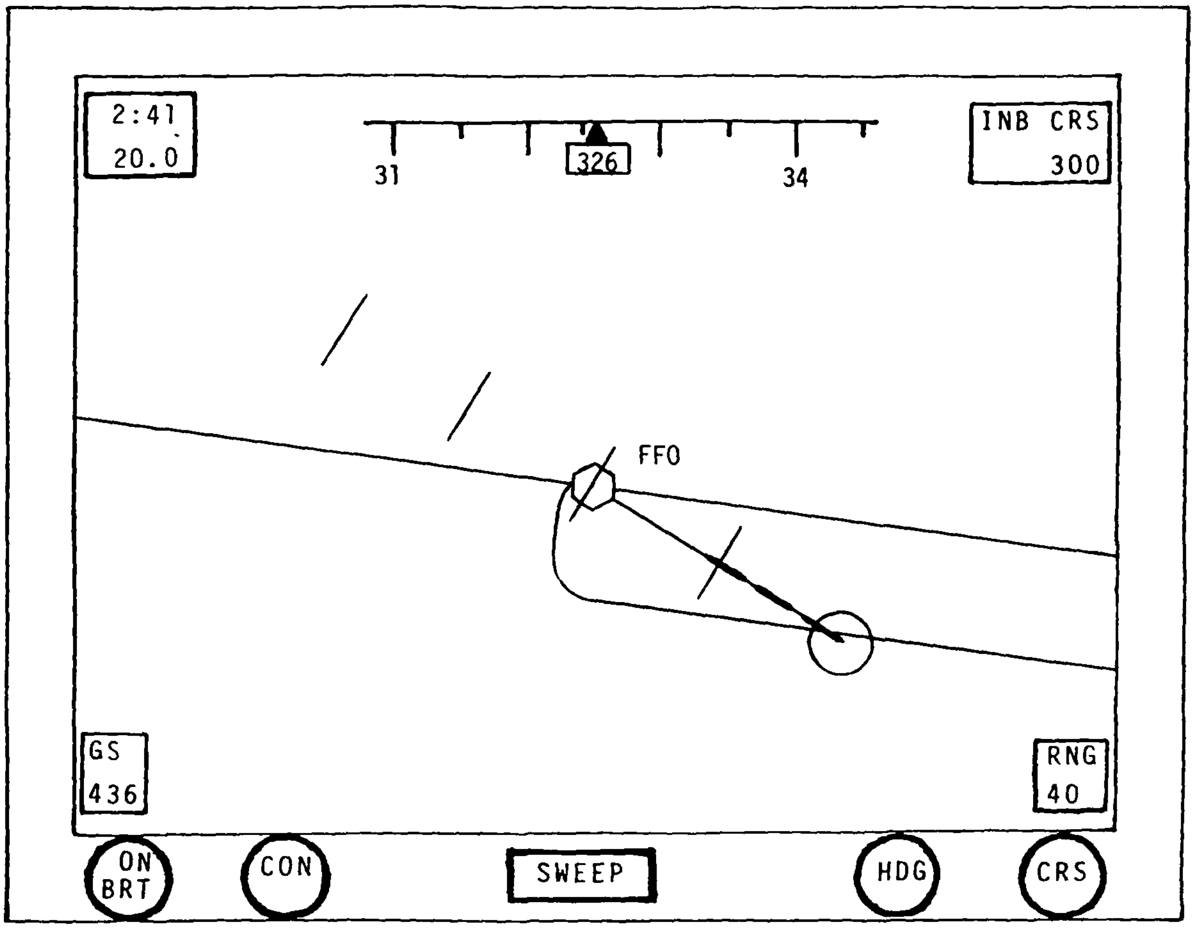
INB CRS	030
INB LEG/TURNS	10/L
REC TAS/DFT CR	
REC IP	
TURN RNG/OFFSET --/10	
PUSH TO INSERT	

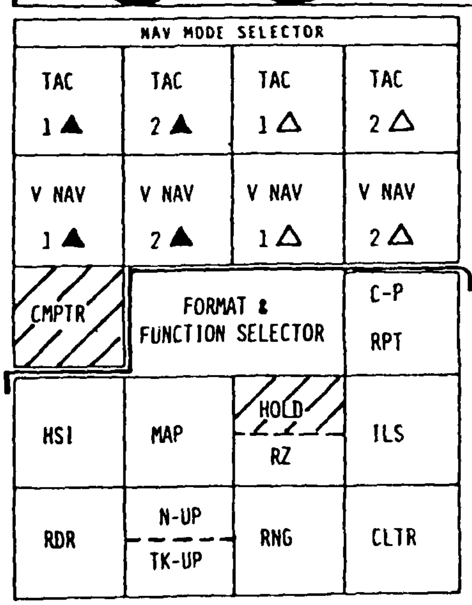
NOTE:

- North up format automatically displayed when HOLD is selected.
- INB CRS is the holding pattern course inbound to holding fix.
- Radar in GND MAP mode.
- Radar cursor switch activated.

Figure 11

HSD HOLD FORMAT





HSD MODE SELECTOR SWITCHES

NAV MGT HOLD/RZ PAGE PROGRAMMED AS:

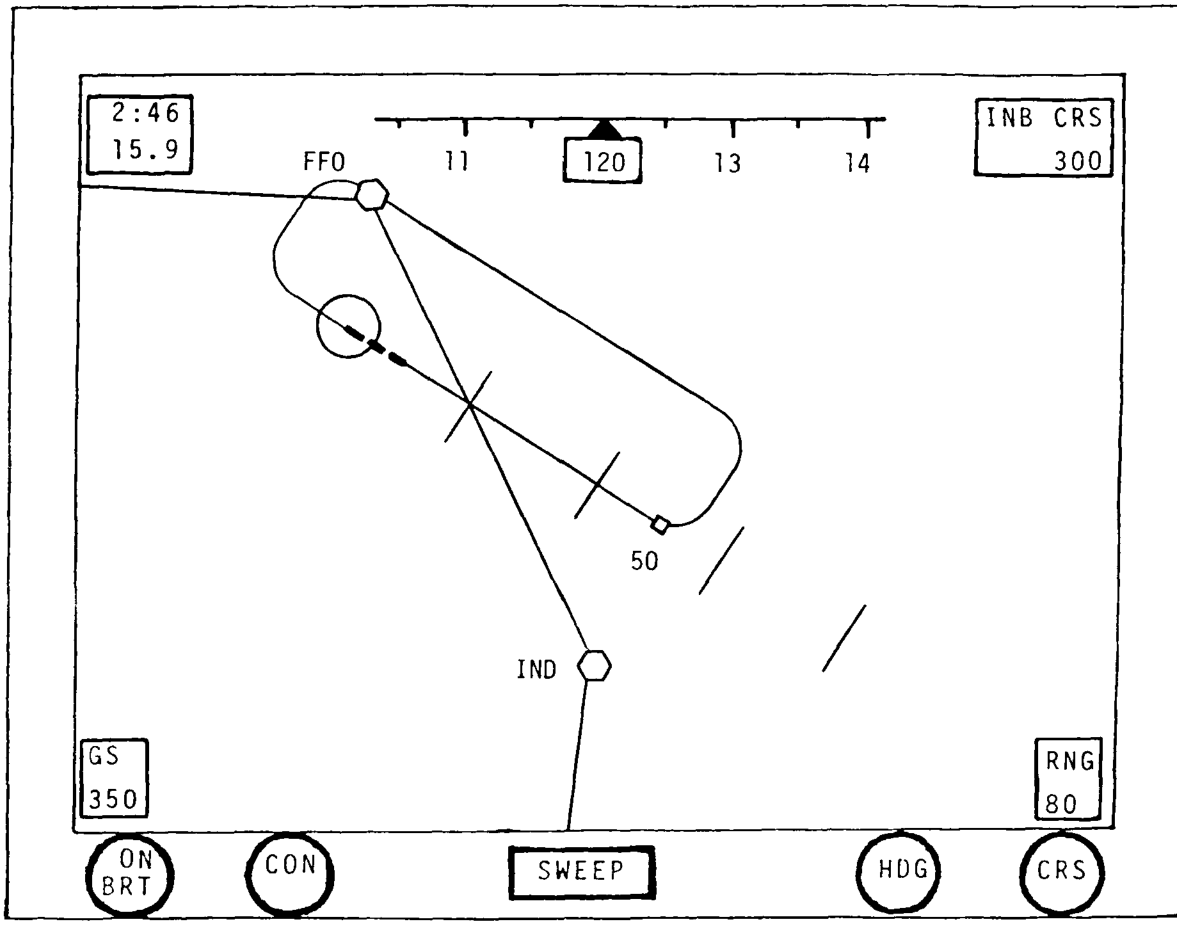
INB CRS	300
INB LEG/TURNS	50/L
REC TAS/DFT COR	
REC IP	
TURN RNG/OFFSET	--/20
PUSH TO INSERT	

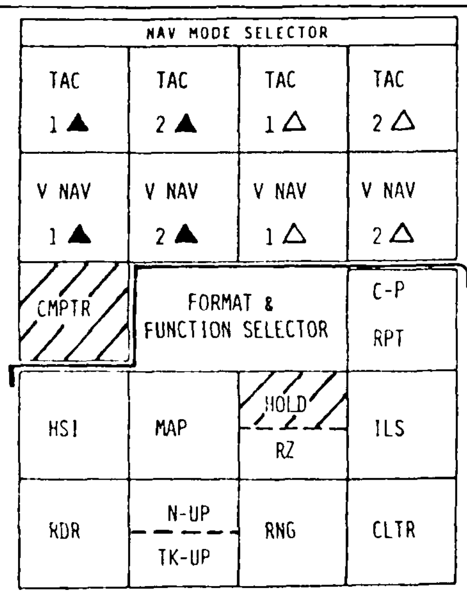
NOTE:

- North up is automatically displayed when HOLD is selected.
- INB CRS is the holding pattern course inbound to the holding fix.

Figure 12

HSD HOLD FORMAT



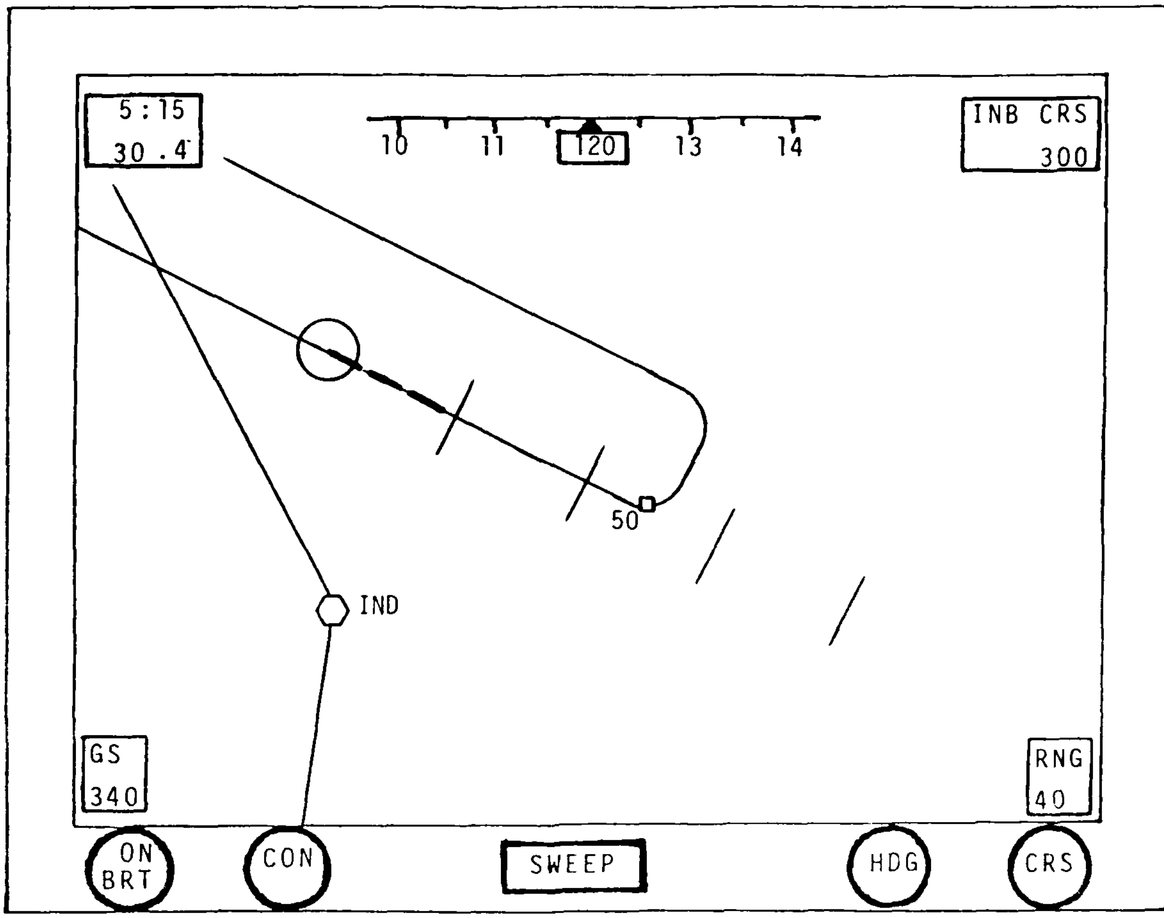


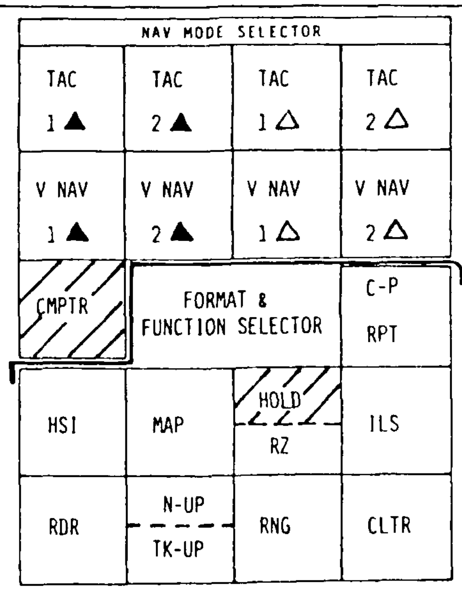
NOTE:

- North up format is automatically displayed with HOLD format.
- INB CRS is course inbound to holding fix.
- Length of inbound leg (50) as typed on the HOLD/RZ page of nav management system, is displayed adjacent to a point where inbound turn is started.

Figure 13 HSD MODE SELECTOR SWITCHES

HSD HOLD FORMAT





HSD MODE SELECTOR SWITCHES

NOTE:

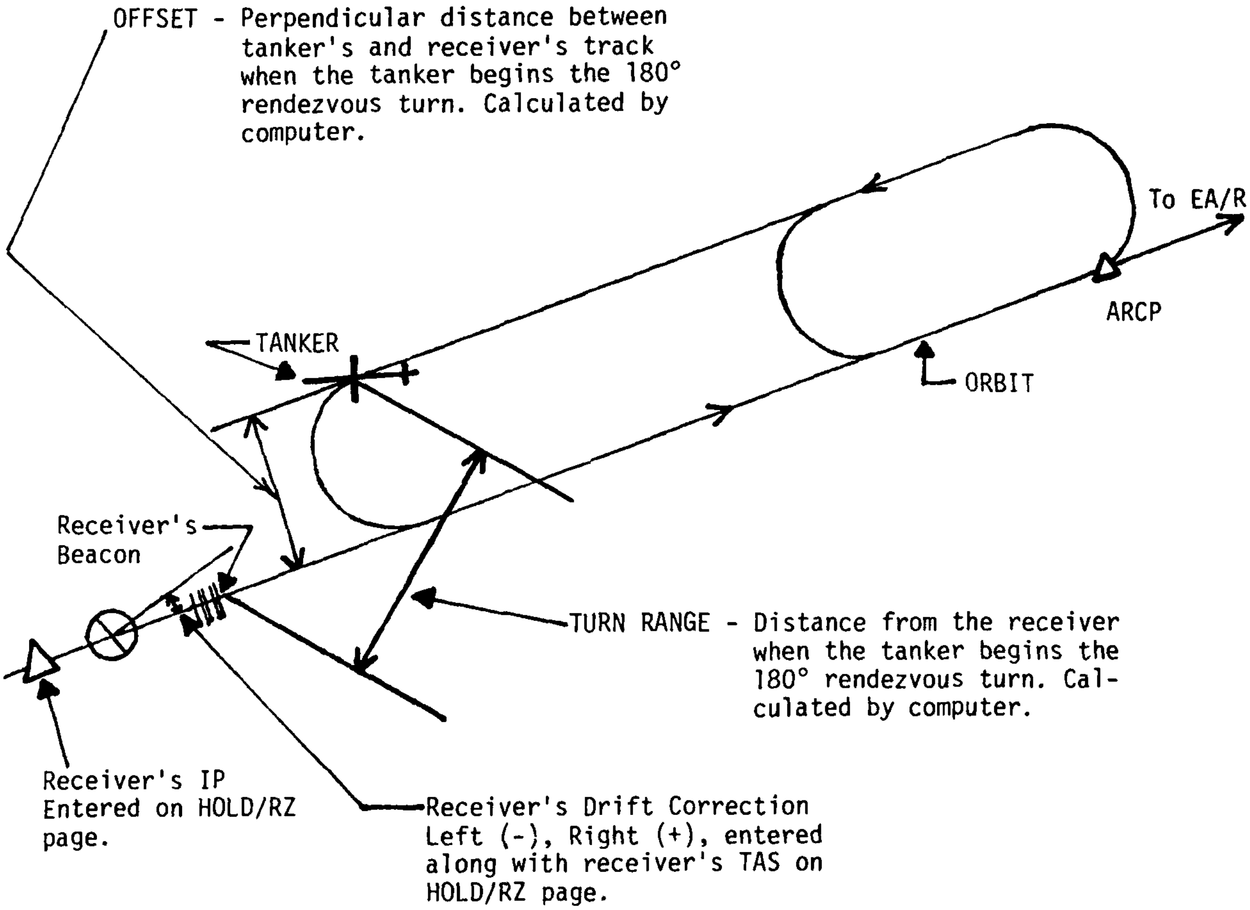
- North up format is automatically displayed with HOLD format.
- INB CRS is the holding pattern course inbound to holding fix.

Figure 14

Figure 15 depicts Point Parallel Rendezvous.

Figures 16 and 17 depict some of the possible point parallel rendezvous format variations which may be displayed on the HSD. The sequence shows the tanker as it approaches the receiver (beacon) and prepares to make its 180° turn inbound. Figure 8 could occur later in this sequence after "MAP" has been selected on the HSD format selector switches.

POINT PARALLEL RENDEZVOUS

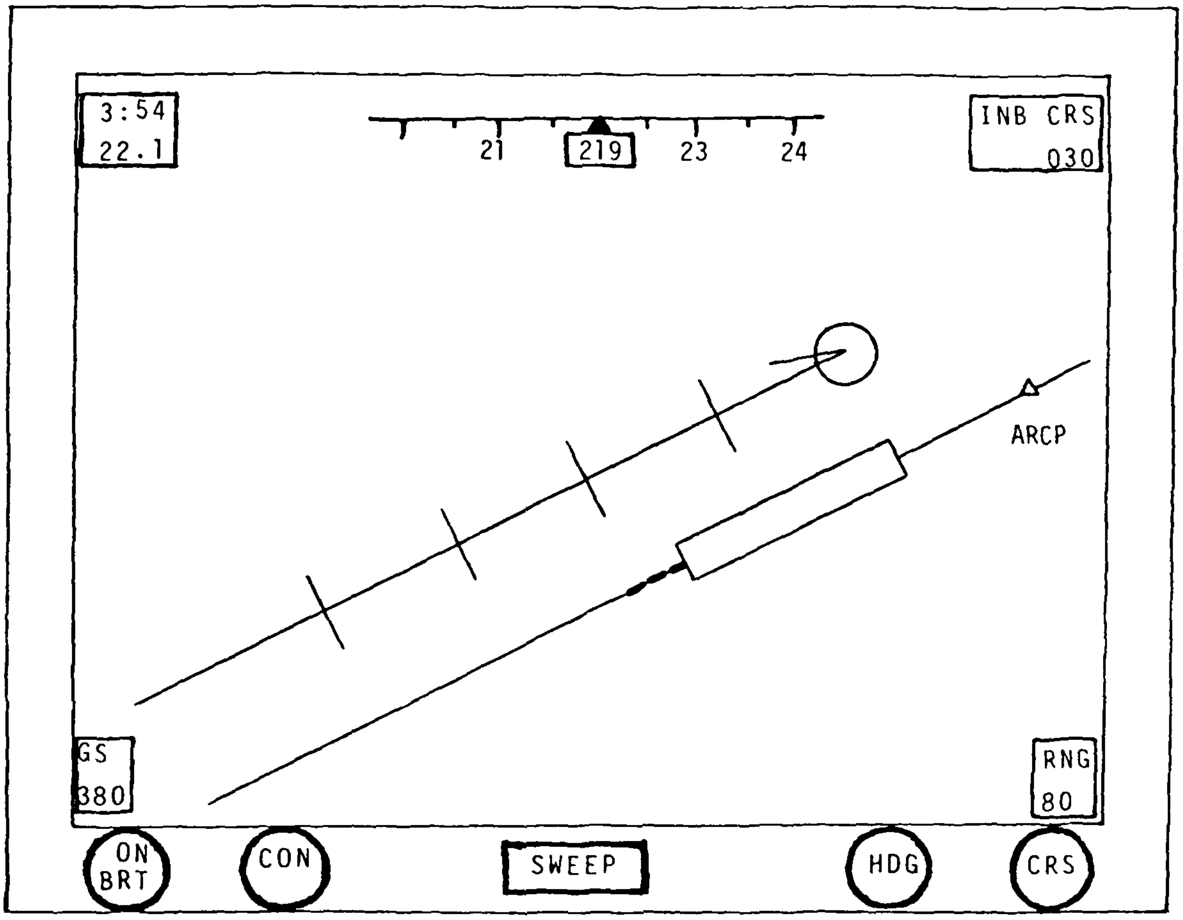


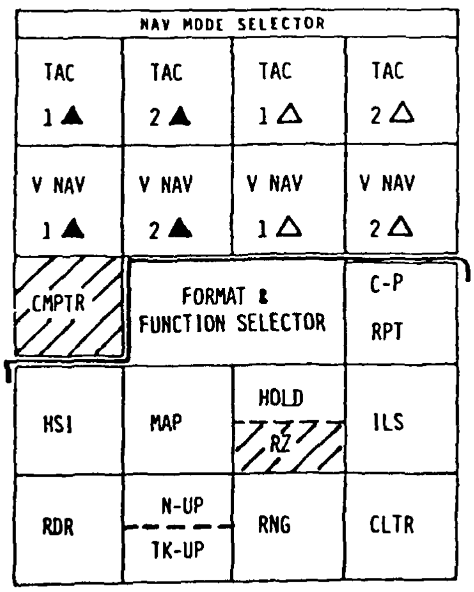
NOTE:

- This diagram is furnished to depict the definition of terms and is not a format that will be displayed.

Figure 15

HSD RZ FORMAT





HSD MODE SELECTOR SWITCHES

NAV MGT SYSTEM PROGRAMMED AS:

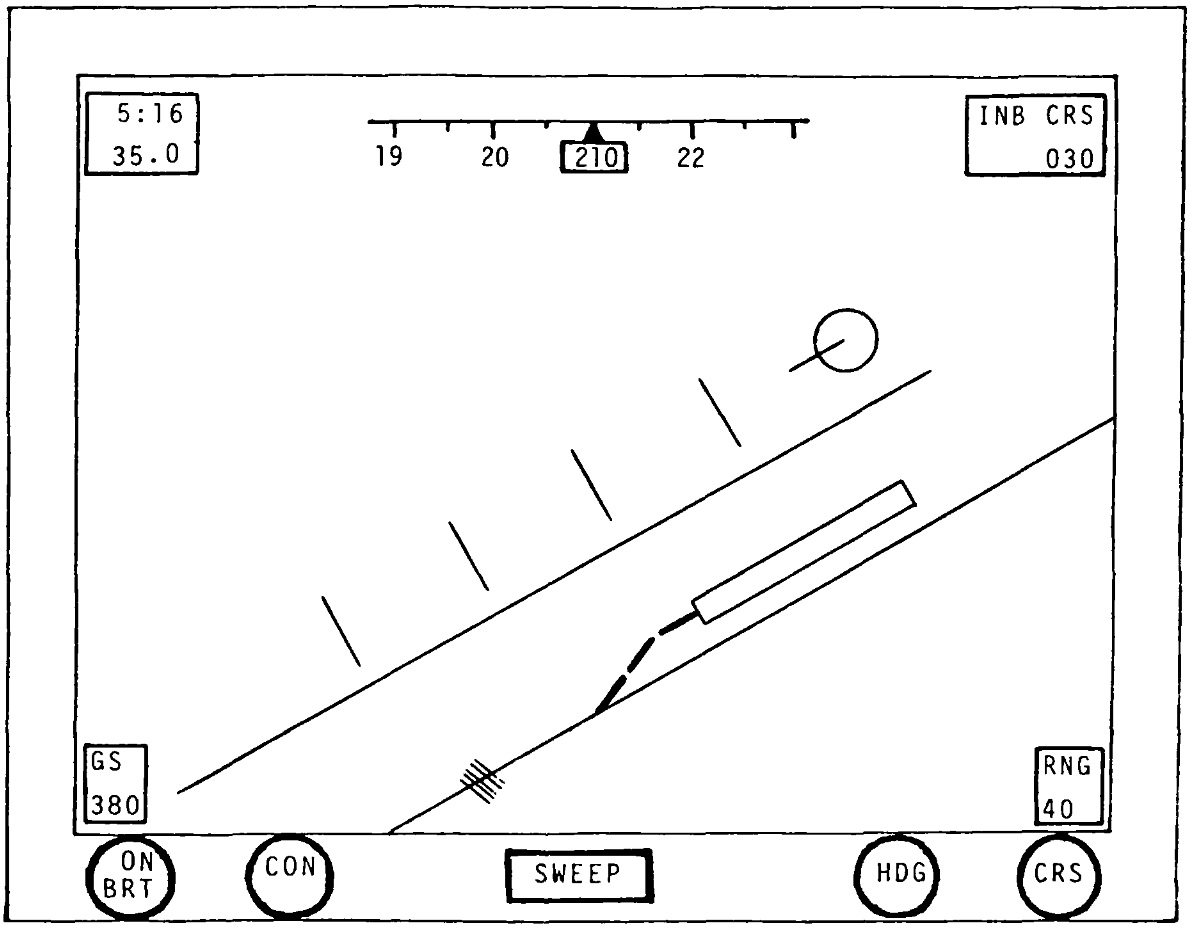
INB CRS/TYPE	030/R
INB LEG/TURNS	--/L
REC TAS/DFT CR	440/-5
REC IP	N403520 E0321630
PUSH TO INSERT	

NOTE:

- North up format is automatically displayed when RZ is selected.
- INB CRS is course inbound to ARCP.
- Predictive vector lines are now displayed at the leading edge of the TURN RANGE/OFFSET symbol paralleling ground track.

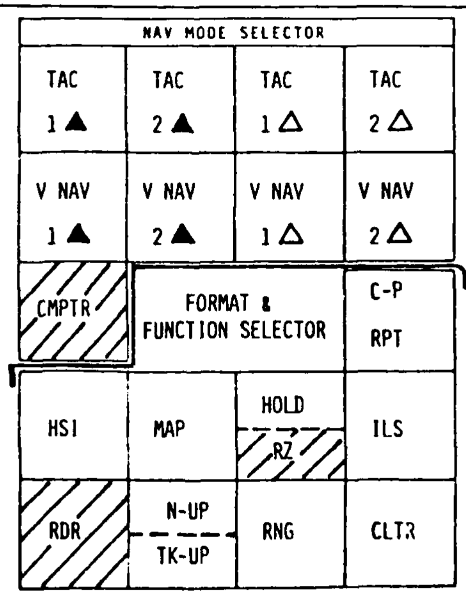
Figure 16

HSD RZ FORMAT



NOTE:

- Aircraft has just started a left turn toward reciprocal (210°) of inbound course (030°).



HSD MODE SELECTOR SWITCHES

NOTE:

- North up format is automatically displayed when RZ is selected.
- INB CRS is course inbound to the ARCP.
- Predictive vector lines are now displayed at the leading edge of the TURN RANGE/OFFSET symbol.
- Radar is in Beacon mode.

Figure 17

d. ILS - ILS information can be displayed on either the conventional HSI format or a modified MAP format.

(1) Obtain the ILS HSI Format (Figure 5) as follows:

With the Nav Mode selector in CMPTR and the HSD format selector switch in HSI, MAP or HOLD/RZ, pressing the ▲ (BRG and CDI) VHF NAV or TACAN switch causes (1) the CMPTR light to go out, (2) the pressed switch to activate (illuminate), (3) permits manual tuning of TACAN RT units through the control head, (4) automatically changes the HSD format to an HSI display, and (5) illuminates the HSI format switch. TACAN, VOR or ILS can then be flown with the HSI format.

Note: No ♠ (BRG pointer) is displayed with the ILS format; however, ⇧ (BRG/DIST-NO CDI) pointer selections may be made.

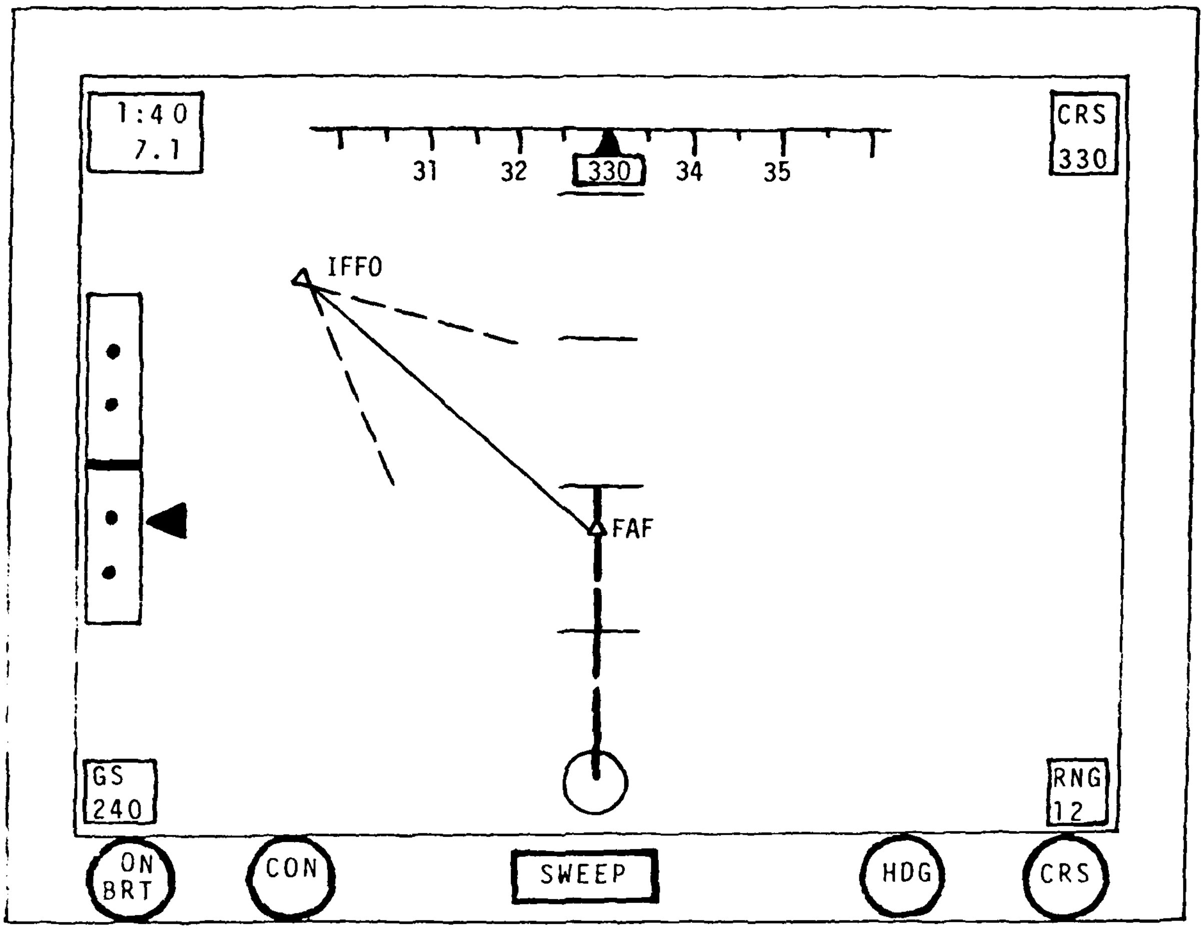
(2) The ILS MAP Format rather than the HSI format can be displayed as follows:

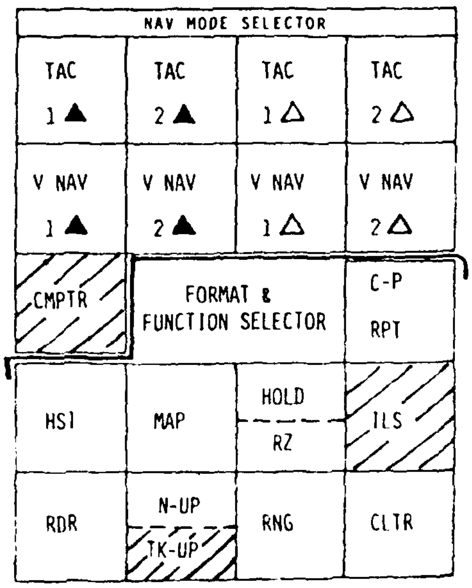
With the Nav Mode selector in CMPTR (light on), pressing the ILS HSD format switch (light on) causes the HSD display to disappear unless or until an ILS frequency (odd frequencies from 108.1 through 111.9 mHz) is manually tuned in one of the VHF NAV receivers. The frequencies in both receivers will be scanned by the computer. The #1 VHF NAV frequency has priority over #2 VHF NAV if both are tuned to ILS frequencies. If and when an ILS frequency is tuned in either receiver, the ILS MAP format is displayed. If or when a VOR frequency is tuned in both receivers

(even frequencies 108.0 through 111.8 and all frequencies 112.0 through 117.9 mHz) with ILS format selected, both V NAV switches will blink and the ILS symbology will disappear (glideslope indication and final approach fan).

Figures 18, 19 and 20 depict some of the possible ILS MAP format variations which may be displayed on the HSD. The sequences shows an aircraft on an ILS approaching an airfield.

HSD ILS FORMAT





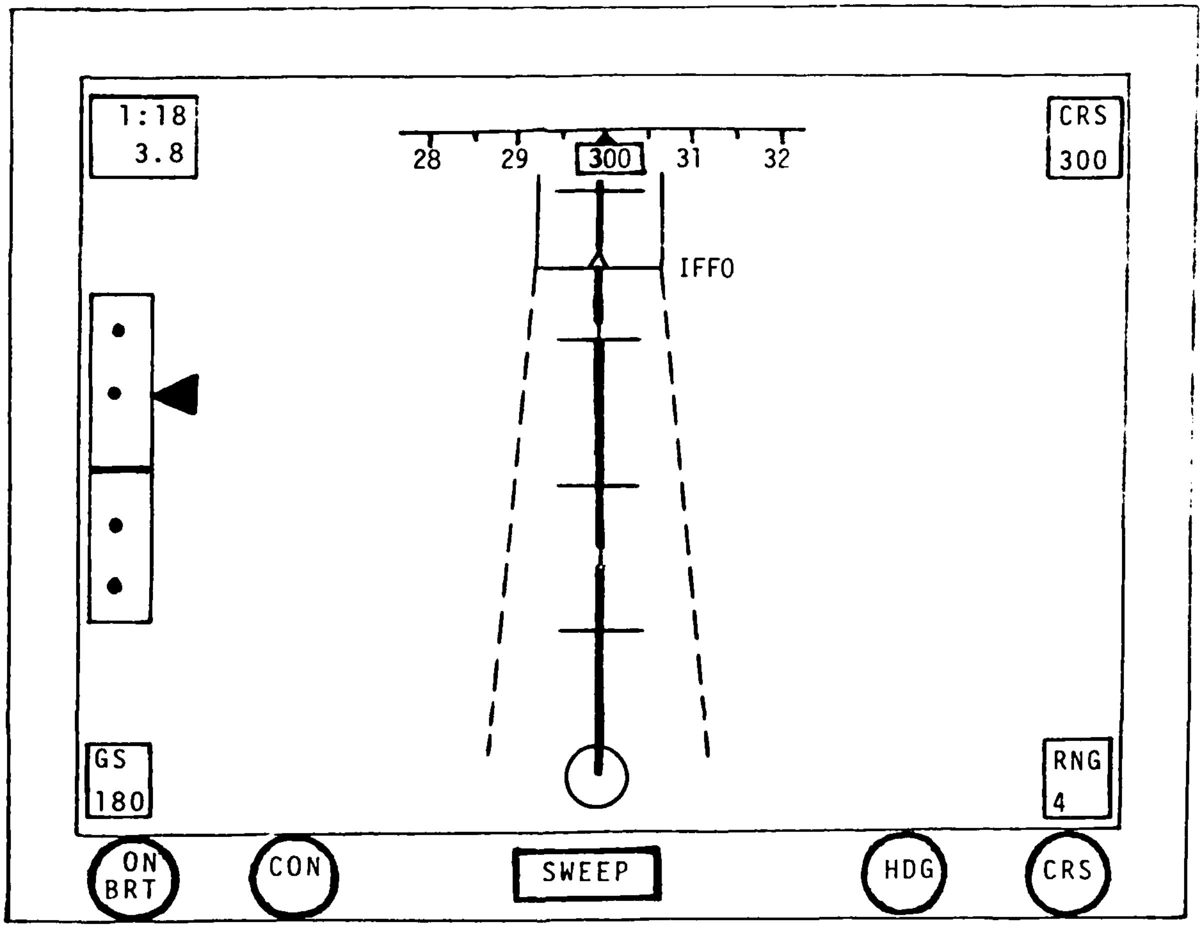
HSD MODE SELECTOR SWITCHES

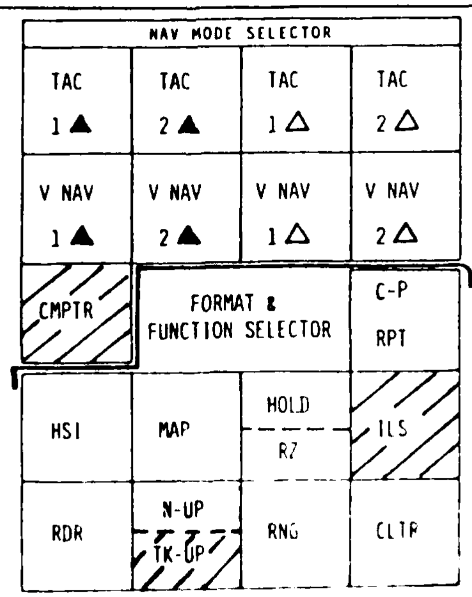
NOTE:

ILS frequency tuned in VHF NAV 1 or 2 (ILS frequency not tuned in either R/T unit causes both ▲V NAV switches to blink and ILS glide slope and final approach fan to disappear.

Figure 18

HSD ILS FORMAT





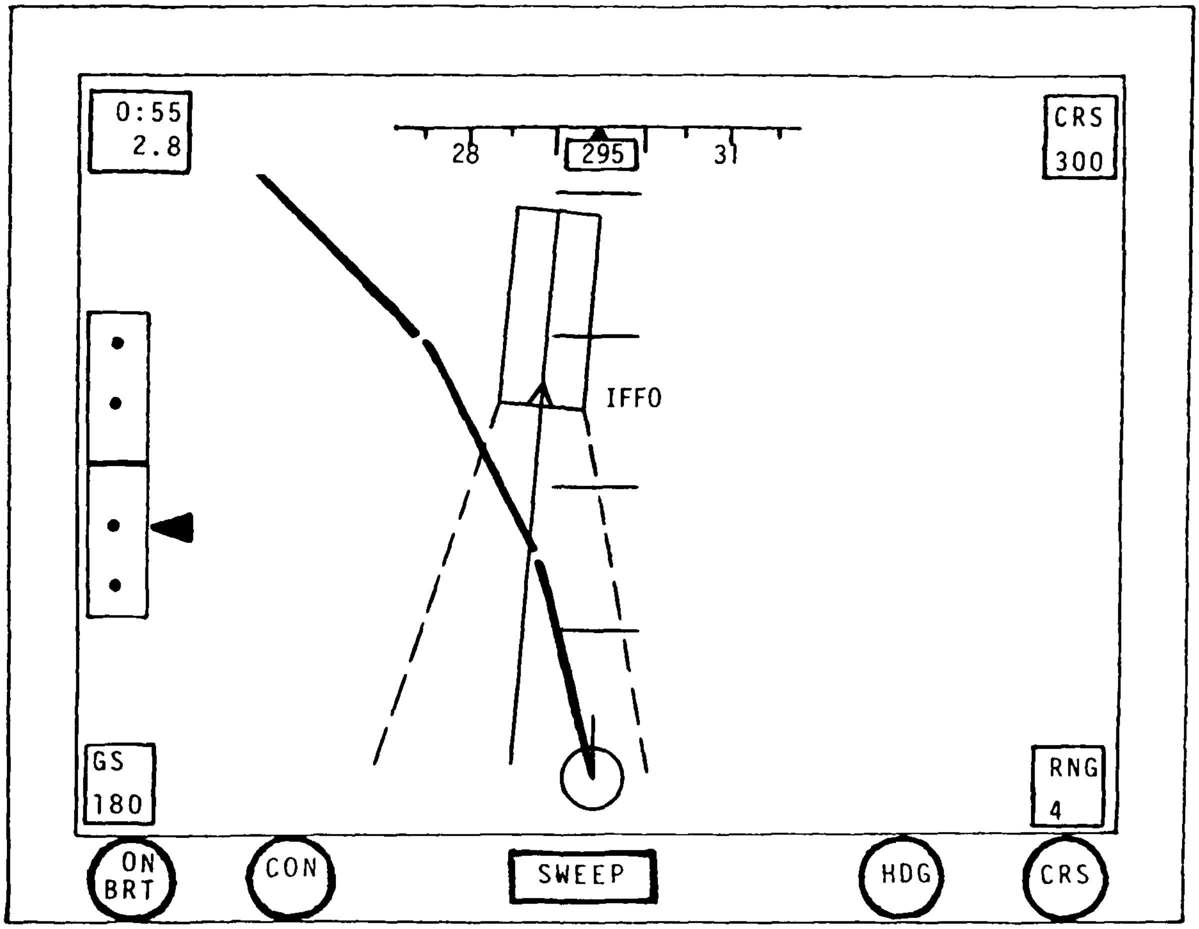
HSD MODE SELECTOR SWITCHES

NOTE:

- ILS frequency tuned in VHF NAV 1 or 2

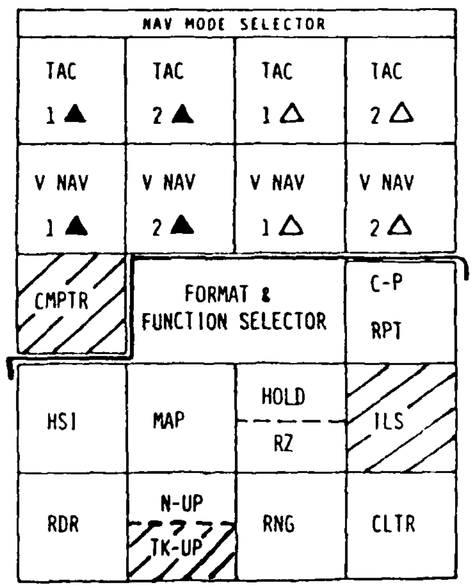
Figure 19

PILOT HSD ILS FORMAT



NOTE:

- Aircraft is to the right of localizer, in a left bank and will intercept localizer in 30 seconds.
- Aircraft is above glideslope.



HSD MODE SELECTOR SWITCHES

NOTE:

- ILS frequency tuned in VHF NAV 1 or 2

Figure 20

3. The operation of the Function Selection switches is as follows:

a. RADAR - Selection of this switch causes radar information, as determined by the position of the RADAR Mode Selector switch to be displayed on the HSD. Radar information (weather, ground map and beacon modes), may be overlayed on any HSD format except HSI, or may be selected by itself. The range of the displayed information is either scaled to be compatible with the format being overlaved or selected with the RANGE/SCALE switch. Due to limitations in the simulator, the radar range cannot be varied between the pilot and copilot. Whenever radar is selected by both pilot and copilot the scale on both displays will go to that selected by the pilot. The radar cursor control and display is discussed in paragraph 4.

b. N-UP/TK UP (North/Track-Up) - Selection of this function reorients the displayed format to either a north or track-up presentation. Activation of the switch will cause a north-up presentation to change to track-up, or a track-up presentation to change to north-up accompanied by appropriate lighting of half of the switch. The function is only compatible with the MAP and ILS formats. The display automaticallv changes to N-UP for HOLD or RZ. When the format changes, the N-UP or TK-UP remains the same until the switch is cycled.

c. RANGE - Selection of this alternate action switch causes the range and scale of the displayed information to change. Generally, the HSD format automatically changes range to a preselected value as each different format is selected. The programmed ranges are: MAP - 160 NM, HOLD/RZ - 80 NM, ILS - 12 NM. The range of the displayed information is changed by pressing the RANGE switch. Each press of the switch changes the range to the next higher predetermined value. The first press after the highest value has been selected causes the lowest value to be selected in a wrap-around feature. The total range and distance between range marker values (in NM) when radar is displayed are 4/1, 12/3, 40/10, 80/20, 160/40 and 240/60.

d. CLTR (Clutter) - Selection of this switch either adds or deletes computer generated navigation information from the MAP, HOLD/RZ or ILS display formats. If unwanted, the information is removed by depressing the switch. Conversely, if not present but desired, pressing the switch will cause the information to appear. The various stages of clutter/declutter are: (1) basic map symbology, (2) (1) plus TACANS, (3) (2) plus all other NAV AIDS, (4) (3) plus airfields and obstructions. The switch has a wrap-around feature so that pressing it again obtains (1).

e. CP-RPT (HSD Repeat switch) - This switch is labeled "CP-RPT" on the pilot's panel and "P-RPT" on the copilot's panel. When the "CP-RPT" switch is pressed by the pilot, the information

being displayed on the pilot's HSD will be replaced (identically) with the information being displayed on the copilot's HSD and the switch light will illuminate. The pilot's remaining HSD mode/ format selector switches turn off. C-P RPT switch is mutually exclusive with all other HSD mode and format selection switches. Vice versa applies to the copilot's use of the HSD repeat switch.

4. The function of other related controls are described below.

a. CRS SET (Course Set) - This knob (located below the HSD) performs the same function as the Course Set knob located on the HSI on the existing KC-135. However, it is only operable with the ▲ (BEARING + CDI) Nav Mode Selector switches selected and the HSD in the HSI mode. In all other switch combinations, the knob is declutched, with course information being generated by the computer based on the pilot programmed flight plan.

b. HDG SET (Heading Set) - This knob (located below the HSD) performs the same function as the heading set knob on the existing KC-135. It controls the heading markers (which is a part of the HSI format) regardless of the NAV mode being utilized. The heading marker may also be moved with the heading slew switch on the control yokes. This slew switch moves the heading marker 1^{o} per switch contact. If the heading slew switch is held down for more than 1/2 second, the heading marker is slewed at 18^{o}/sec. The heading slew switches work individually (pilot's yoke switch

moves pilot's heading marker, etc.) when the slew switch on the overhead panel is selected to "Single" or together (either pilot's or copilot's switches move both heading markers) when the slew switch is selected to "Dual". The heading marker provides input to the flight director when the "Heading" mode is selected on the flight director.

c. SWEEP CONTROL - When pressed, this rocker type switch (located below the HSD) causes a cursor line to project from the nose of the aircraft symbol on the HSD. The sweep will remain visible for as long as the switch is held down plus 5 seconds. It will move at 5°/second in a fan shaped pattern, in the direction that the rocker switch is being held, 90° either side of the nose of the aircraft. The number of degrees between the displayed sweep and the longitudinal axis of the aircraft is displayed digitally near the lower center edge of the HSD. It can be used to determine the amount of aircraft heading change necessary to approach or avoid a specified target.

d. RADAR CURSOR CONTROL - A radar cursor control is located on the forward center console. When cursor is selected, a cross hair appears on the display. The cross hair or cursor can be moved about the display with a joy stick type cursor control and positioned at a desired location. The position of the cursor can be inserted into the nav management system through the cursor

insert control switch. For example, when a ground target is identified, the cursor can be moved to a position over that target with the cursor control. The insert function can be activated by pressing the insert switch, which feeds this information to the mission computer. The computer then calcualtes the relative location of the aircraft and the cursor. This information can be automatically or manually used by the pilot to update the navigation system.

e. RADAR WEATHER WARNING - The radar system contains an automatic feature which displays a warning symbol (flashing "WX") on the HSD of nearby weather cells if the radar is on the WX or WX CTR position even though a radar overlay is not being displayed on the HSD. This allows the pilot to select RADAR on the HSD to determine the exact location.

5. The Bearing Distance Heading Indicators (BDHI's) are described here although they are not part of the HSD. The selection of Nav aid information to be displayed on the BDHIs integrated with that displayed on the HSD provides a more complete picture. The source of the bearing and/or bearing distance information displayed on each BDHI is not selectable. The single bar needle (#1) on the pilot's BDHI provides information from TACAN #1. The pilot's double bar needle (#2) provides information from the UHF/DF. The copilot's single bar needle (#1) is connected to TACAN #2. The copilot's double bar needle (#2) is connected to the low frequency ADF.

☆U.S.Government Printing Office: 1980 — 657-084/765

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